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This thesis is submitted in fulfillment of academic requirements for the award of the degree of Master of Science in Water Resources and Environmental Management (WREM).

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CERTIFICATE

This is to certify that the Project work entitled "Performance Evaluation of Water Supply Services in Kigali City is a record of the original bonafide work done by HAKIZIMANA THEONESTE (Reg.No.220020088) in partial fulfill of the requirement for the award of Master of Science in Water Resources and Environmental Management of College of Science and Technology ,University of Rwanda during academic year 2023-2024.


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DECLARATION

I, THEONESTE HAKIZIMANA, do hereby declare that this research project, being submitted to the University of Rwanda for the degree of Master of Science in Water Resources and Environmental management, is my own original work that satisfies the University of Rwanda's Code of Academic Integrity and other pertinent policies, procedures, rules, and regulations. It hasn't been submitted to any other institution previously by me or any other person in full or in part fulfillment of the requirements for the attainment of any qualification.

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DEDICATION

I dedicate this Dissertation To Almighty God For the love, grace and mercy To my parents who encouraged and gave me support, To my beloved wife MUTONI OLIVE and To my future family For your immeasurable love, guidance, and care. I respect to all who are dear.

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Abstract

This study aims to evaluate the performance of water supply services in Kigali City, focusing on key aspects such as demand fulfillment, customer satisfaction, impacts of water shortages, and water quality compliance. The objectives of the study are fourfold:(1)To evaluate whether the water supply meets the daily demands of homes and business in Kigali City,(2)To measure the level of satisfaction among customers with the water supply services,(3)To assess the main impacts of water shortage on residents of Kigali City ,and (4)To ensure that the quality of final water delivered to customers complies with established water quality standards.

The methodology employed in this research includes both quantitative and qualitative approaches. Data collection was conducted through household surveys, and field observation to gather comprehensive insights into water supply situation. Additionally, water quality tests were performed to verify compliance with established standards. The household surveys aimed to capture customer satisfaction levels and the perceived impacts of water shortage. The Kigali water supply system produced 120,476,413 L/d in 2023, below the initial demand of 390,612,280 l/d. Customers were mostly satisfied with the taste and smell of water, but dissatisfied with the color. The survey results showed 48.75% of respondents rated water bills as average, 28.44% as high, 11.56% as very high, and 11.25% as low. All respondents agreed on the need to address access to clean and safe water for all.

The finds from this study are expected to provide valuable insights into the current performance of Kigali's water supply services, highlight areas requiring improvement, and inform policy decisions to enhance water service delivery in the City. By achieving these objectives, the study aims to contribute to the overall goal of ensuring reliable and high water quality supply for all resident of Kigali City.

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Abbreviations and Symbols

%	Percentages.
E-Coli	Escherichia coli.
EWSA	Rwandan Energy Water and Sanitation Authority.
L	Liter
mg	milligram
g	gram
Cm	centimeter
Max	maximum
m ³	cubic meter
°C	Degree Celsius
µS	Micro Siemens
cl ⁻	chloride
EC	Electro conductivity
KWN	Kigali Water Network
M	Molarity
PH	Potential of Hydrogen
GIS	Geographic Information System.
TDS	Total Dissolved solid
NTU	Nephelometric Turbidity Unit
Mg/l	Milligram per litre
BOD	Biological oxygen demand
DO	Dissolved Oxygen
MININFRA	Ministry of Infrastructure
NRW	None Revenue Water
RPHC	Rwanda Population and Housing Census
RURA	Rwanda Utilities Regulatory Authority
RWASCO	Rwandan Water and Sanitation Corporation
UfW	Unaccounted for Water
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development

WASAC	Water and Sanitation Corporation
WDNs	Water Distribution Networks
WDS	Water Distribution System
WHO	World Health Organization
Q1,	First quarter of year
Q4	Fourth quarter of year
KTTR	Kigali Tap Test Result
S	Sample

CHAPTER1. INTRODUCTION

1.1. General introduction

Water utilities' primary responsibilities are building, operate, and maintaining water supply systems (Ajibike, 2013). Several international organizations, like the American Water Works Association, have provided clear instructions on how to assess these utilities' performance (Kayaga, et al., (2004)

A severe water shortage in Kigali city has been observed in some parts of the city especially in Kinyinya, Bumbogo, mu Makawa, Gihogwe, Karuruma, Jabana, Jali na Gatsata, Busanza, kanombe and Ndera. Water shortages have been a persistent problem in Kigali City's water supply, which are frequently ascribed to a variety of factors.

A study by Ntiruhungwa et al. (2018) discovered that the main causes of water scarcity were the fast population growth and the inadequate infrastructure. Furthermore, Umugwaneza & Nshimiyimana (2020) identified seasonal variations, water pollution, and inefficiencies in water distribution systems as significant contributing factors.

In developing nations such as the United States, where water development is primarily driven by the government, the inability to establish effective water supply systems has been attributed to a combination of factors (Sulemanova, 2002). Getting the money needed to create, maintain, and grow the systems is probably the most crucial of them (UNEP, 2002; Hall, 2006). The financial resources available, particularly for daily operations and upkeep, are statistical given the low level of public funding for urban development, which includes water supply (WHO, 2000; UNICEF, 2000).

Generally speaking, government parastatals in these nations handle the water supply with the twin goals of earning money to cover expenses and offering a social service. Paradoxically, the majority of these parastatals still rely on state governments for subsidies because they are unable to cover their operating costs with their own income (Hall, 2006). Research has additionally verified that approximately 50% of the water in developing countries' drinking water supply systems is lost as a result of leaks, unauthorized connections, and vandalism. (UN, 2002; Hall, 2006) Furthermore, low pay, inadequate supplies and equipment, and unclear institutional goals have all been mentioned as typical institutional traits of water supply organizations in developing nations (World Bank, 1994; Franceys, 1993).

The fastest growing cities in SSA include Kinshasa, Lagos, Accra, Johannesburg-Pretoria, Nairobi, Luanda and Dar es Salaam. The rapid population growth in urban areas in SSA is also associated with the increase of problems such as economic crisis, inadequate water supply, and growing waste production.(Saghir et al. 2018) .

In Africa, just 4% of rural households have access to piped water, while 38% do so in urban areas. These sources like wells and boreholes provide water to the majority of rural households in Africa. Compared to poorer households, wealthier households are significantly more likely to have piped water available to them. Growing income is linked to piped water and a decrease in reliance on wells, boreholes, and surface water on the water supply ladder (Alaazi et al 2019). Customers of water utilities want water services delivered in an adequate and reasonable quality, protecting the environment and public health, at the lowest feasible cost(AWWARF, 1998).One crucial component of domestic water supplies is the quality of the water that is delivered to and used by households; this factor affects hygiene and, consequently, public health (WHO, 2003). Any water utility's ability to satisfy its customers depends on how well these systems are operated and maintained, both quantitatively and qualitatively, with the highest possible level of customer satisfaction (Bernard et al, 2006).

Shared vision, values, and mission; strategic planning; human resources development; program development management system; organizational culture; governance; legal/fiscal; compliance; monitoring and evaluation accountability; and all of these factors are critical to the effectiveness of water utilities in any country (UI Haq and Shalid, 2007).

Kigali is home to a million people but only 30% of households were connected to the city's mains water network. With connection rates increasing and urban development advancing rapidly, the city needed reliable, sustainable sources of supply plus improved wastewater management and treatment infrastructure.

The report shows that access to improved drinking water sources has increased in Rwanda, from 70 to 74 percent Kigali City which is described to have the largest percentage of households using an improved drinking water source which is mostly piped into their premises (EICV 3 THEMATIC REPORT,2022).In Rwanda 44.4 % of water supplied within all branches as of March 2020 was water losses due mainly to illegal connections, leakages, road construction, metering inaccuracies, meter bursts, meter blocked, natural disasters and stealing water by moving meters. Including Kigali water supplied (m³) was 7,957,346, Water sold (m³) was 4,454,649 and none

revenue water (NRW) was 3,502,697 m³ these showed that the NRW is equal to 44 % (Report for water and sanitation statistics, 2020). Shortages in the water supply and declining quality are two issues that need more focus and action (Ayoade, 1981). Every day, new tactics are being developed to ensure that everyone has access to water. However, the disparity between the supply and demand of water keeps growing as a result of inadequate infrastructure combined with fast urbanization and population growth (Bernard et al, 2006).

1.2. Statement of Research Problem

The water supply sector in Kigali city faces many problems, partly due to poor operations and service delivery systems. Since the establishment of Kigali Water Works under The Water and Sanitation Corporation (WASAC), who has the responsibility for the water supply under the supervision of the Ministry of Infrastructure (MININFRA), the sector has gradually been modernized through the establishment of an autonomous regulatory body and the introduction of government participation, private sector, which encourages user participation. Therefore, it is necessary to ensure sustainable operation and maintenance.

The trend towards private sector involvement in urban water supply marketing and service provision is currently growing fastest in Kigali; one of the most notable water infrastructure projects in Rwanda is the Kigali Bulk Water Supply Project. The project, completed in 2015, includes the construction of a new water treatment plant and a pipeline network to transport water from the Nyabarongo River to the city of Kigali. A thorough analysis and assessment are desperately needed, as evidenced by the evaluation of Kigali City's water supply service performance.

There are still a number of issues that need to be looked at in detail in order to properly assess the current situation, even with continuous efforts to improve the infrastructure and services related to water supply. The main concerns that call for an evaluation are outlined in this problem statement. The following problems show how urgent a comprehensive assessment is:

Inadequate Service Dependability: In certain areas of Kigali City, there are still instances of irregular water supply and frequent service interruptions, which negatively affect locals, businesses, and vital public services. The irregular supply of water creates serious obstacles to day-to-day operations and impedes the growth of the economy.

Infrastructure Deficits: Kigali's current water supply infrastructure has problems with outdated

infrastructure, insufficient capacity, and upkeep. These elements raise the possibility of system failures, leaks, and inefficiencies.

Fairness in Access Differences: Kigali City's various neighborhoods and demographic groups continue to have varying degrees of access to water supply services. To make sure that all citizens have fair access to a consistent supply of water, an assessment is required to pinpoint and resolve these disparities.

Efficiency of Operations: It is necessary to examine the water supply management system's overall operational efficiency, including billing systems, accurate metering, and responsive customer service. Improving these functional aspects is essential to maximize customer satisfaction and resource utilization.

Quality Issues: Water quality concerns, such as problems with contamination, inconsistent testing, and treatment methods, cast doubt on the portability and safety of the water provided to inhabitants. Public health critically depends on ensuring that people have access to safe and clean drinking water.

Ability to Support Population Growth: As the population of the city continues to rise, an evaluation of the water supply system's ability to accommodate the expanding demands is necessary. In order to avoid water shortages and guarantee sustainable service delivery, it is imperative to anticipate and prepare for future population growth.

1.3. Aim and Objectives

The aim of this research is Evaluation of the performance of water supply service in Kigali city and the objectives to be achieved for this study are:

- To evaluate if the water supply meets the daily demands of homes and business in Kigali city.
- To measure the level of satisfaction among customers with the water supply services.
- To assess the main impacts of water shortage on the residents of Kigali City
- To ensure the quality of final water delivered to customers complies with established water quality standards.

1.4. Justification of the Study

This study is expected to identify/contribute, especially by providing knowledge, new information on the Kigali water supply Services. It will also continue to serve as reference data for any further investigations and is also useful for academic purposes.

This study will allow the researcher to assess expectations regarding water quantity service delivery and contributing to the success and sustainability of the Kigali Water Woks project. It will provide useful ideas to better improve urban water supplies in developing countries. Finally, this research will stimulate research in new and under-researched areas that can provide useful data to inform policy formulation, planning decisions and policy advocacy efforts at local and other levels.

1.5. Scope of Study and Limitations

The scope of this study is to assess and evaluate the performance of the water supply service in Kigali City, with a focus on identifying key areas of concern and improvement. The study was encompass various aspects related to the water supply system, aiming to provide insights into its reliability, efficiency, and effectiveness in meeting, the demand of residents and businesses and the quality of water served in the city. The study was concentrated on Kigali City, Rwanda's largest and capital city, the objective is to document the range of experiences and difficulties encountered by citizens and companies throughout the city. The study was involved data collection, analysis, and reporting over a predetermined period of time.

The results of this study will enhance knowledge about Kigali City's water supply service performance and how it affects locals' daily lives and businesses. For the purpose of making well-informed decisions and enhancing the quality of service delivery, policymakers, water supply authorities, and other stakeholders will find great value in the insights the results offer.

CHAPTER 2: LITERATURE REVIEW

2.1. Background.

In 1987, a decree (Arrêté Présidentiel n°291/11 du 15 mai 1987) transferred ownership of rural water infrastructure to districts, well before the government enacted a comprehensive decentralization policy. From 1950 to 1984, beneficiaries received free water in rural areas, and the national government owned the infrastructure. (FOA- AQUASTAT, 2005) Reconstruction activities following the 1994 genocide did not result in a significant increase in water supply and sanitation coverage, nor was there a long-term management model for rural water systems. Many users did not pay for water, some collected funds were mismanaged, and volunteers on water committees in charge of operating and maintaining systems were frequently unmotivated. As a result, approximately half of rural water schemes did not function in 2004, according to an extensive field survey (MINITERE, 2008)

In 2004, the government declared its support for public-private partnerships; locally started PPPs quickly expanded, and by 2007, they accounted for 25% of rural water systems. The government and a private company inked a 27-year contract in March 2015 to invest \$75 million and supply the capital Kigali with 40,000 cubic meters of bulk water per day from a well field near the Nyabarongo River (WASAC, 2015). However, 66% of people living in urban areas and 57% of people living in rural areas had access to an improved source of drinking water, according to the 2005 Integral Household Living Conditions Survey. It was estimated that only 10% of urban areas and 8% of rural areas had access to adequate sanitation (EICV, 2005)

In 2000, total water use in Rwanda was estimated at 150 million cubic meters (5.3×10^9 cu ft), with domestic use accounting for 24% (36 million cubic meters (1.3×10^9 cu ft) per year). This equates to only 4 cubic meters per capita per year or 11 liters per capita per day (FAO-AQUASTAT, 2005). Between 1990 and 1993, the country was engulfed in a civil war, which was followed by genocide in 1994 so that the government has set the target of achieving universal access to water supply and sanitation by 2018 (MINITERE, 2008). Rwanda's urban water supply and sanitation are managed by the Water and Sanitation Corporation (WASAC). Its predecessor EWSA had more than 118,000 water customers in 2013, up from 38,500 in 2005 (EWSA, 2014). In partnership the European Union (EU) signed a contract with the Rwandan government in 2005 for a major water project in the Bugesera Region

(Kigali rural) worth 16 billion Rwandan francs (Euro 23.24 million). The water project was benefiting the four districts of Kanzenze, Gashora, Bicumbi, and Kanombe in the east of Kigali city.

As of June 2013, the urban water tariff was RWF240 per m³ for the first five cubic meters per month, and RWF300 per m³ for consumption between 6 and 20 m³ per month. Higher tariffs are levied for increased consumption. Water at public kiosks costs RWF240 per m³ (EWSA, 2014)

2.2. History of Rwanda water supply Utility.

In Rwanda, water is distributed by a company called WASAC. ELECTROGAZ, the company's original name, has been in operation as a national utility since 1976. The Rwanda-Urundi water, electricity, and gas utility "REGIDESO" was founded in 1939 and has its headquarters in Bujumbura. It provides water, electricity, and gas to the country. Later, in 1963, the business was split into REGIDESO Rwanda and REGIDESO Burundi. REGIDESO Rwanda changed its name to ELECTROGAZ, a state-owned monopoly, in 1976. In order to manage and restructure ELECTROGAZ in conjunction with Hamburg Water Works for a period of five years, the government entered into a management contract with Lahmeyer International in 2003.

In 2009, the Rwandan Water and Sanitation Corporation (RWASCO) was established, marking the institutional separation of water supply and energy; however, it was absorbed into the Rwandan Energy Water and Sanitation Authority (EWSA) just a year later. In 2008, RWASCO signed a three-year agreement with the National Water and Sewerage Corporation (NWSC) of Uganda for performance improvement and to promote commercial service delivery. In 2014, the urban water Sector was again separated from the energy sector, creating a water and sanitation utility that is now known as WASAC (WASAC, 2015)

Rwanda's water supply and sanitation systems are distinguished by a well-defined governmental policy and substantial donor backing in reaction to the low quality of services and the unreliability of rural water systems.

2.2.1. Responsibilities WASAC group

The regulatory agency Rwanda Utilities Regulatory Agency (RURA), created by law in 2001, is responsible for the economic regulation of the telecommunications, electricity, water, sanitation, gas and transportation sectors. Its mission is to:

- Ensure that certain utilities provide goods and services throughout the country to meet in transparency all reasonable demands and needs of all natural persons and organizations;
- Ensure that all utility suppliers have adequate means to finance their activities;
- Continually promote the interest of users and potential users of the goods and services provided by utilities so that there is effective competition when competition is introduced in each utility sector and protection of users from abuses of monopoly positions is ensured because certain public utility sectors have a monopoly over the market.
- Facilitate and encourage private sector participation in investments in public utilities;
- Ensure compliance by public utilities with the laws governing their activities.

The purpose of the agency's water and sanitation department is to:

- regulate in a way that promotes fair competition, sustainable and efficient use of water resources;
- ensure better quality of services to customers at fair prices;
- Ensure effective protection of environment by enforcing wastes disposal and by-products treatment regulations.

WASAC is a product of reforms and institutional development of the former Energy, Water and Sanitation Corporation (EWSA). The Water and Sanitation Corporation (WASAC) is a limited liability Corporation registered under the company law of Rwanda with the Government as a sole proprietor/shareholder. WASAC is responsible for the growth and development of the water and sanitation sector with the mission of Providing quality, reliable and affordable water and sewerage services through continuous innovations and detailed care to our customers' needs and vision of to be the most sustainable Water and Sanitation Utility in Africa, exceeding stakeholder's expectations.

2.2.2. Overview of Water treatment plants of WASAC group in Kigali.

Karenge WTP was established in 1975 with processing capacity of 3,840 cubic metres (135,608 cu ft) every day. In 1985, that capacity was increased to 7,200 cubic metres (254,266 cu ft) daily. In 2008, daily output was increased to 12,000 cubic metres (423,776 cu ft). As of October 2020, the system produced 15,000 cubic metres (529,720 cu ft) of drinkable water every day, of which 12,000 cubic metres (423,776 cu ft) (80 percent) was piped to Kigali and 3,000 cubic metres (105,944 cu ft). The plant supply treated water in two areas: 1 .Kigali network; by 85 % (Remera,Kanombe. Kabeza, Masaka, Kabuga;Ndera; Free Zone & AZAM) 2. Rural area; by 15 % including Karenge Sector; Nzige Sector; Gahengeri Sector; Muyumbu Sector and Nyakariro Sector (Mininfra,2023)

Kimisagara Water Treatment Plant supplies clean water to City of Kigali. It is located in Kimisagara cell, Nyarugenge District and is one of the three water treatment plants supplying the city dating back to the 1980s. It produces 29,000 cubic meters daily. Five pumping pipes transport the water to three pipes from the plant to reservoirs and it distributed water areas of Towncenter,Gasyata, Nyamirambo,Kimihurura, Muhima ,Biryogo Kwa nyiranuma(wasac,2020.) Nzove I&II water treatment plants are located in Kanyinya Sector, Nyarugenge District. Nzove water treatment plant currently supplies 61,000 cubic meters of water per day, while it has capacity of producing 105,000 cubic meters per day. Nzove I distributed water in areas of Kicuciro ,Kagarama , Kahanga ,Karuma ,Runda , Mbweravura ,Remera , Gisozi , Gacuriro ,Kagugu,Kinyinya,Kibagabaga/Nyarutarama(wasac,2023).

Kanzenze water treatment plant is located in Bugesera district and it produced 40,000 m³/day , then supply 30,000 m³/day to Kigali and 10,000 m³/day to Bugesera. Areas distrusted in kigare are: Kicukiro, Remera, Kimironko, Kabeza, Kanombe, Busanza, Nyarugunga, Kigali Special Economic Zone, Ndera, Nyamata, Kanzenze-Karumuna,(mininfra,2021)

2.3. The Problem of Urban Water Supply.

Access to sources of clean water and equitable distribution are essential components of evaluation. Research conducted by Mutabazi et al. (2019) shows that efforts to increase access to marginalized areas have progressed, guaranteeing a more equitable distribution of water supply. However, issues pertaining to the disparities between rural and urban areas as well as service accessibility in times of emergency require additional attention (Karekezi et al., 2018). Water shortages have been a persistent problem in Kigali City's water supply, which are frequently ascribed to a variety of factors. A study by Ntiruhungwa et al. (2018) discovered that the main causes of water scarcity were the fast population growth and the inadequate infrastructure. Furthermore, Umugwaneza & Nshimiyimana (2020) identified seasonal variations, water pollution, and inefficiencies in water distribution systems as significant contributing factors.

Customer satisfaction depends heavily on how fair and accurate the billing and metering systems are. Precise metering is essential to prevent irregularities and guarantee that consumers are charged fairly, according to Nzabarinda & Shingiro (2019).

Admits increases in customer satisfaction and billing accuracy. Assuring affordability, particularly for households with low incomes, is still difficult (Ndahayo et al., 2017). Research has also shown that in order to avoid mistakes and inconsistencies, metering equipment needs to be maintained on a regular basis (Haguma, 2016) Resolving problems and enhancing service quality are greatly aided by efficient customer service and communication. In their assessment of Kigali City's water supply services, Uwamahoro et al. (2021) emphasized the value of prompt customer service and effective complaint resolution. It highlighted how important it is to have better response times and communication channels.

2.3.1. Kigali water supply challenges & proposed solution.

According to a 2020 report by the African Development Bank Group (AfDB), Kigali's water infrastructure is struggling to keep up with urbanization, resulting in inadequate coverage and service interruptions.

The Ministry of Infrastructure's "Water Supply and Sanitation in Rwanda" report (2019) emphasizes the importance of significant infrastructure investments to increase access to piped water, particularly in peri-urban and informal settlements. The University of Rwanda conducted research in 2021 that revealed disparities in water access between affluent and low-income

neighborhoods in Kigali, with marginalized communities facing greater challenges. A study published in the *International Journal of Environmental Research and Public Health* (2022) emphasizes the importance of equitable distribution policies for addressing social inequalities in water access. According to the Rwanda Environmental Management Authority (REMA), pollution from industrial activities and inadequate sanitation infrastructure are major factors influencing water quality in Kigali (2021).

A World Health Organization (WHO) study published in 2020 highlights the health risks posed by contaminated water sources, emphasizing the critical need for improved water treatment and management practices. The IPCC report (2021) emphasizes the vulnerability of African cities such as Kigali to climate change, including changes in rainfall patterns and increased frequency of droughts. *Climatic Change* (2022) highlights the importance of climate-resilient water infrastructure and adaptive water management strategies in mitigating the effects of climate change on water resources.

The World Bank's "Rwanda Urban Development Project" (2020) identifies limited financial resources as a major impediment to improving Kigali's water supply infrastructure. The International Water Management Institute (IWMI) issued a policy brief in 2019 calling for innovative financing mechanisms and strengthened public-private partnerships to close the funding gap in water infrastructure development.

2.4. Efficiency and Infrastructure evaluation

2.4.1. Efficiency in water supply services

In order to minimize waste, minimize operating expenses, and optimize resource utilization, water supply services need to be efficient. According to Foster and El Asfahani (2020), efficiency is a multifaceted concept with technical, economic, and managerial components. Reducing water losses requires technical efficiency, which entails streamlining distribution systems and water treatment procedures (Nhamo et al., 2019). Cost-effectiveness, tariff policies, and financial sustainability are the main focuses of economic efficiency (Hutton et al., 2015). Within water supply organizations, managerial efficiency encompasses effective resource allocation and decision-making.

The Prime Minister of Rwanda Dr. Edouard Ngirente says that according to the water needs in the city of Kigali up to now, all the residents of this city have access to clean water, but that there are still obstacles of the old water pipes.

He said this on Monday, May 6, 2019, when the Nzove I water treatment plant, which produces 40,000 cubic meters per day, was commissioned. Normally the water available in the city of Kigali was 95 thousand cubic meters per day (95,000m³/day), however 143,668 thousand cubic meters per day is needed.

However, Prime Minister Dr. Edouard Ngirente says that there are residents of Kigali city who do not have access to clean water for various reasons. Among these reasons are small and old water pipes, the fact that the population of Kigali continues to increase, and the infrastructure that needs water is also increasing day by day due to the rapid development of the city. The prime minister says that the rapid development of the city has not been accompanied by the rapid development of water infrastructure, because it takes a lot of time. (Kigali today news, 2019).

2.4.2. Evaluation of infrastructures

Analyzing infrastructure entails looking at the material resources that make up the water supply system. This comprises distribution systems, storage facilities, water treatment plants, and related machinery. Numerous studies stress that in order to guarantee dependable service delivery; infrastructure must be regularly maintained and renovated (Smeets et al., 2017). In order to solve problems like leaks and system failures, aging infrastructure—especially in older cities—presents challenges and calls for focused investments (World Bank, 2019). Technological innovations, like the use of sensors and smart meters, are essential to the management and monitoring of infrastructure (Nhamo et al., 2019).

2.4.3. Reducing Water Loss and Optimizing Distribution

Water supply services face a serious problem with water losses, which are frequently the consequence of leaks and inefficient systems. Improving efficiency primarily aims to reduce these losses. To maximize water distribution networks' efficiency and reduce losses, a number of strategies have been used, such as pressure management, leak detection systems, and real-time monitoring (Nhamo et al., 2019). By lowering excessive water consumption, sustainable methods like demand-side management and water conservation campaigns also increase

efficiency (Rusca et al., 2016). For continuous service, infrastructure upkeep and dependability are essential. According to a study by Uwamahoro et al. (2018), routine maintenance is crucial to preventing service disruptions and water loss. In the third quarter 2023, the quantity of water billed was 12.5 million cubic meters in comparison to 10.9 million cubic meters sold in Q3 2022, which represents an increase of 14.5%. The billed water has also increased by 22.6% in comparison to the second quarter of the year 2023(WASAC report, 2023).

Table 2.1: water billed (m³) from third quarter (Q3) 2022 to third quarter (Q3) 2023

location	Q₃ 2022	Q4 2022	Q1 2023	Q2 2023	Q3 2023
Kigali city	6559468	6008077	6134283	6305782	7484671
Bugesera	602049	778282	600741	615803	790007
Gicumbi	97858	73052	85550	77853	113835
Huye	351673	337227	319509	323433	393060
Karongi	93814	85052	90242	91125	108672
Muhanga	219066	191335	196713	200150	217599
Musanze	644513	541674	586650	581336	763568
Ngoma	156917	118760	125960	130339	180271
Nyagatare	422096	294307	339614	359388	515044
Nyamagabe	119322	111413	106815	102876	140708
Nyanza	199625	189641	189531	187934	237292
Rubavu	543985	474815	507405	474673	596187
Ruhango	118193	121864	115127	111295	144176
Rusizi	217871	185033	178116	181020	220027
Rwamagana	603047	472933	479390	475291	626988
Total	10949497	9983465	10055646	10218298	12532105

Source: WASAC reports

Table 2.2. Water supplied (m³) into network from third quarter 2022 to third quarter 2023

location	Q ₃ 2022	Q ₄ 2022	Q ₁ 2023	Q ₂ 2023	Q ₃ 2023
Kigali city	10806713	10674462	10738745	10690676	11592106
Bugesera	1032366	1010850	1023870	1018669	1109299
Gicumbi	193116	191711	200359	192219	198614
Huye	601567	601034	569942	597102	626877
Karongi	200105	207802	187217	163910	158907
Muhanga	333340	355604	307444	332961	330376
Musanze	847768	852284	770609	803690	753470
Ngoma	204420	245378	207833	193868	199678
Nyagatare	681413	893429	836537	838726	891810
Nyamagabe	242407	213164	175369	183546	205582
Nyanza	227437	283101	294745	295436	296382
Rubavu	1035537	1062529	1031975	1115372	1056372
Ruhango	294085	275665	293621	290198	280690
Rusizi	390808	384544	344649	347543	366003
Rwamagana	625997	895236	855443	757954	773433
Total	17335821	18302498	17783500	17856118	17811369

Source: WASAC reports

2.4.4. Improvements in Technology and Effective Infrastructure

The way infrastructure is managed and maintained has changed as a result of the integration of contemporary technologies like data analytics, smart meters, and remote monitoring. Smart infrastructure projects facilitate the collection of data in real time, which enhances system performance, identifies problems more quickly, and lowers maintenance expenses (Nhamo et al., 2019). Additionally, these developments enable proactive system optimization and improved predictive maintenance.

2.5. Water Supply Sustainability

2.5.1. Integrated water resources management.

Integrated Water Resource Management (IWRM) is the foundational idea of sustainable water delivery. To guarantee fair access and protect ecosystems, integrated water resources management (IWRM) places a strong emphasis on the coordinated development and management of land, water, and related resources (UN, 2015). In an effort to balance water supply, environmental protection, and stakeholder needs, sustainable water delivery systems frequently adhere to IWRM principles (Rusca et al., 2016).

The city of Kigali as capital has more than 3 million people, as many other parts of urban areas in Rwanda they always complain about the shortage of water. In Urban area water supplied is estimated at 187,293m³ per day and water demand is 290,038m³ per day. There is a gap of 102,745m³ per day which results in water rationing in some urban areas. The topography is the main cause of water shortage in Kigali city and some other parts, as people located in at the highest point are more affected by non-availability of water supply. (wasac.rw,2020)

2.5.2. Appropriate Conservation and Use of Water

Water delivery that is sustainable also includes efforts to conserve water and use it responsibly. Demand-side management and water conservation initiatives have been used to lower water consumption in areas where there is a water shortage (Gupta et al., 2019). One of the most important components of sustainable water delivery is encouraging industries and consumers to adopt water-efficient practices (Prathima et al., 2018). Systems for reusing and recycling water improve conservation efforts even more (Smeets et al., 2017).

Table2.3: Water Consumption (m³) in Rwanda

Category	2018-2019	2019-2020	2020-2021	2021-2022	2022-2023
1.Industries	1,490,064	1,533,972	1,653,534	1,866,159	2,041,495.63
2.Residential	18382185	17393887	19429778	22571743	24,692,491.17
3.Non-residentisl	8839530	8297441	8398414	9976187	10,913,508.51
4.Public tapes	2,081,253	2,360,232	2,700,512	2,886,564	3,157,773.69

Source: WASAC reports.

2.5.3. Equity in Access and Social

A key element of sustainability is guaranteeing fair access to water distribution networks. Reducing gaps in water access between urban and rural areas is a key component of sustainable development goals, as is reaching out to marginalized and underserved populations (World Bank, 2019). Developing community awareness, practicing responsible water use, and encouraging social equity in water delivery are all part of the UN's 2015 water delivery policy. Parthimas et al. (2018) assert that fair service delivery is facilitated by efficient channels of communication and complaint response procedures.

2.5.4. Cost recovery and financial sustainability.

For water delivery systems to remain viable over the long term, financial sustainability is crucial. Upgrading infrastructure and paying for operations requires creative financing solutions, equitable tariff structures, and responsible fiscal management (Hutton et al., 2015). Financial sustainability is ensured in part by revenue-generating methods and public-private partnerships (Gupta et al., 2019).

WASAC is one of the government agencies that invest a large amount of money in order to implement major water distribution, sanitation and hygiene projects. As per the revised budget for the year 2021/2022, this institution was allocated 42.8 billion Rwandan francs. It is a state-owned trading company [for water trading]. The report of the Auditor General of Public Finance in the year 2020/2021 showed that WASAC has lost about 19 billion Rwandan francs since its establishment in 2014. In an interview IGIHE had with the Acting General Director of WASAC, Eng. Uhumuza Gisèle, expressed that although the huge losses caused by the leaking water have not reached the customers, some of the users have not paid, which has led to a debt of three billion Rwandan francs. He said, “Until today, WASAC is only trading water. The first loss that the Auditor-General points out is about water leaks. He collects it and shows that 'in the treated water, a certain part was not able to be sold because it broke on the way but there are also buyers who did not pay us. (igihe.com, 2022)

2.6. Service Delivery and Customer Satisfaction

2.6.1. A Customer-First Mentality.

Understanding and satisfying the needs of customers is a key component of a service delivery approach known as "Customer-First Mentality." Studies highlight that customer engagement and satisfaction are key factors for successful water supply services (Prathima et al., 2018). This strategy incorporates accessible services, effective channels of communication, and individualized services catered to the preferences of each individual customer (Haguma, 2016).

2.6.2. Channels for Effective Communication

Customer satisfaction depends on having efficient channels of communication. It is ensured that customers are informed about service updates, maintenance schedules, and billing procedures through prompt and transparent communication. Research suggests that effective and transparent communication raises customer satisfaction and trust (Uwamahoro et al., 2021). Digital platforms, like online portals and mobile apps, have grown in importance as communication and engagement tools (Nzabarinda & Shingiro, 2019).

2.6.3. Addressing and Resolving Complaints

One important aspect of providing services is handling complaints in an effective and sympathetic manner. In order to address customer concerns, it is imperative to have both streamlined complaint resolution processes and responsive customer support. Research indicates that timely and transparent issue resolution is crucial because unresolved complaints have a big influence on customer satisfaction (Uwamahoro et al., 2021). According to Nzabarinda and Shingiro (2019), customer feedback mechanisms and complaint management systems are crucial instruments for enhancing the quality of service provided.

2.6.4. Accurate and transparent billing

Accurate and transparent billing is crucial to establishing trust and guaranteeing client satisfaction. According to research, billing irregularities can cause a person to become unhappy and mistrustful (Nzabarinda & Shingiro, 2019). To avoid inconsistencies, water supply companies must consistently audit their metering and billing systems, maintain open and honest billing procedures, and offer comprehensive billing information (Haguma, 2016).

The Economic and Trade Commission in the Parliament of Rwanda has revealed that there are 52,000 water suppliers who are defrauding the National Agency for Water, Sanitation and Sanitation (WASAC) and consumers. This commission, on January 19, 2023, delivered to the General Assembly of the Chamber of Deputies its analysis report on the report made by the State Inspector General on the technology used in WASAC. The president of this commission explained that these 52,000 trees are over 15 years old and should not be used because they are malfunctioning; causing losses to WASAC or consumers.

The lawmaker said that this knowledge caused WASAC to lose more than 40%. He said, in the census, it has been revealed that there are 52,000 trees that are more than 15 years old, which is one of the causes of WASAC's loss of over 40% of its annual income and there are also buyers who may cause loss because they are not counted correctly (Bwiza.com news, 2023)

2.6.5. Customized Products and Services for the Client.

Satisfaction is influenced by positive customer experiences and personalized services. Customers' overall experience can be improved by acknowledging and accommodating their varied needs and preferences through service customization (Prathima et al., 2018). This entails providing adaptable payment methods, advice on conserving water, and prompt customer service. High customer satisfaction is more likely to be attained by water supply companies that go above and beyond what is expected of them (Haguma, 2016). In the swamp between Remera and Kanombe, at a distance of one kilometer from Kigali airport, we found people who came to get water, including some who came from eight kilometers (8Km). They say that they don't get clean water on a regular basis and that's why they came to pump the water from the swamp. The problem of water scarcity every year is more severe during the dry season in the country. In times of rain like this, water is scarce, and many people be saved by the rain. Aimé Muzora said that the scarcity of water is due to the fact that it has to be shared with many people who are increasing every day, especially in Kigali (BBC News 2019)

2.7. Performance indicators for urban water supply systems

Before evaluating the performance of an urban water supply system, it is critical to establish appropriate performance indicators. The following are proposed performance indicators for evaluating urban distribution systems Performance indicators of urban water supply systems (EWRA Water Utility Journal 1:31-40, 2011).

The indicators of an urban water supply system are classified as water resource performance, physical performance, and operational performance. The availability of water resources, as well as the availability of one's own water, is primarily classified as indicators of water performance. Physical performance is measured by storage capacity, transmission and distribution line quality, and metered customer density. Loss management, operation and maintenance, and the quality of water supplied are all considered operational performance.

A study designed to assess the performance of two urban water supply utilities in Tanzania reveals serious water supply issues in the districts under consideration. The assessment was based on two key indicators: service quality and unaccounted-for water. The quality of service and UfW has been identified as key factors influencing the performance of many water utilities. Poor service quality, as measured by water quality, billing efficiency, and customer care, has an impact on consumer willingness to pay, and thus the performance of the water supply utility. The study's methods included a documentary review, household questionnaires, key informant interviews, and field observations. The findings indicate that Muheza town's water supply is less accessible and reliable than Korogwe towns. Customers receive water for an average of 8 hours per day in Korogwe and 5 hours per day in Muheza. Water supplied by the respective utilities in the two districts is significantly less than the total demand. More than 80% of customer complaints in both towns concerned water quality, water scarcity, and customer relations. Poor billing practices and outdated infrastructure have resulted in high UfW figures of 42% in Korogwe and 47% in Muheza. The conclusion was that customers were dissatisfied with the quality of services, and that the UfW was higher than the World Bank's generally accepted value of 25 % (Victor Kimey, 2008).

This research paper evaluates the performance of the Kigali water supply system, not the water utility. The assessment is based on five key indicators: water source availability, hydraulic performance, water quality, customer satisfaction.

2.7.1. Water demand and Coverage in Urban Areas

Water supply coverage paints a picture of a specific country's or city's water supply situation and allows for comparisons between countries as well as inter and intra-city distribution within a specific country. The percentages of the population with or without a pipe water connection are a useful indicator for comparing the coverage of water supply in cities. Although urban areas have better water supply coverage than rural areas, actual water supply coverage in developing countries in general, and African cities in particular, is extremely low when compared to demand.

According to the Global Water Supply and Sanitation Assessment 2000 Report, the largest African cities have 43% house connections or yard taps, 21% served by public taps, and 31% of the population is not served. A household is considered to have access to improved drinking water if it has a sufficient amount of water (20liters/person/day) for family use, at an affordable price (less than 10% of total household income), and is available to household members without requiring extreme effort (less than one hour) per day for the minimum sufficient quantity, particularly for women and children (UN-Habitat, 2003).

In southern African cities, a minimum of 25 liters of potable water per person per day, with a flow rate of at least 10 liters per minute and a source within 200 meters of a household, is considered a basic service (Wallingford HR., 20). In March 2021, WASAC Ltd served 246,941 urban and peri-urban water subscribers, up from 242,497 connections in December 2020, representing a 1.8% increase.

The City of Kigali accounts for 51% of these connections, 49% of them are distributed across the provinces. Rural Water Service Providers serve some people and institutions in the provinces, which explain the difference. At the end of March 2021, the 91.7 % of urban water subscribers are in the category of residential, whereas the remaining 8.3 % are in the category of non-residential, industrial, and public standpipes. (RURA, 2021).

Table2.4: Trends of urban water subscribers per province and City of Kigali

Province	Jun-20	Sept-20	Dec-20	Mar-21
City of Kigali	117,926	121,636	124,234	126,103
Southern province	29,667	30,654	31,212	31,941
Western province	22,159	22,540	22,648	22,962
Northern province	19,651	20,199	20,702	21,174
Eastern province	40,787	42,662	43,701	44,761
Total	230,190	237,691	242,497	246,941

Source: rura- statistic report 2021

In the third quarter 2023, the number of water subscribers served by WASAC Ltd increased from 326,471 as of June 2023 up to 335,442 recorded at the end of September 20223, which represents an increase of 2.7%. The 48.4% of subscribers served by WASAC branches are located in the City of Kigali while 51.6% of them are distributed in the provinces. These water connections include public standpipes serving people without water connection at their homes. The number of connected customers increased up to 335,442 as of September 2023 which shows an increase of 14.8% in comparison to 292,239 connections recorded at the end of September 2022.

Table2.5: urban water subscribers per province and City of Kigali

Province	Sep-2022	Dec-2022	Mar-2023	Jun-2023	Sep-2023
City of Kigali	141,096	145,878	151,372	157,725	162,287
Southern province	39,852	41,717	43,334	44,686	45,880
Western province	29,133	32,119	32,506	32,840	33,453
Northern province	24,785	25,872	26,479	27,208	27,835
Eastern province	57,373	62,366	63,405	64,012	65,987
Total	292,239	307,952	317,096	326,471	335,442

Source: RURA-statistic report 2023

2.7.2. Water Demand Management.

Water demand is the amount of water requested by users to meet their needs. In a simplified way, it is often considered equal to water consumption; however, conceptually the two terms do not have the same meaning (Wallingford HR, 2003).

Most developing countries have a theoretical water demand that is significantly higher than the actual consumptive water use. Water demand management is defined as any socially beneficial action that reduces average or peak water withdrawals or consumption from surface or ground water, consistent with the protection or enhancement of water quality (Tate, 2000). Rothert and Macy (2000) define water demand management as the adaptation and implementation of a strategy by a water institution to influence water demand and usage in order to meet any of the following objectives: economic efficiency, social development, and social equity (Mwendera et al, 2003).

Urban water demand is divided into several categories, including domestic water demand, which includes in-house and out-of-house use, among others. In-house uses include drinking, cooking, sanitation, house cleaning, laundry, and car washing, whereas out-of-house uses include garden

watering, swimming pools, public stand pipes for public use, and fountains, among other things. Urban water demand is typically expressed in terms of liters per capita per day (1/cap/day). Despite the variability in residential indoor water use from household to household, a typical pattern (known as the water use profile) can be developed to provide a reasonable representation of indoor water use, based on the various indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy (Mitchell et al., 2000). Urban water demands in many African cities are frequently non-homogeneous as a result of varying levels of service within the same city. Service levels can range from household connections to standpipes to no service at all (Wallingford HR, 2003).

2.8. Water quality

The word "water quality" refers to the ability of water to sustain various uses or activities. (WHO, 1996) Water quality is influenced by both human activity and natural processes. To prevent and reduce water-related issues, national and international standards for water quality are in place for various reasons such as drinking, personal hygiene, and irrigation. Water quality consists of microbiological or biological, chemical, and physical components.

2.8.1. Physical aspects

Water for drinking should be free of unpleasant tastes, odors, colors, and suspended objects. These are often referred to as aesthetic parameters. Turbidity, color, taste, and odor are all aesthetic criteria that can be detected by the senses. They are significant in monitoring community water supplies because they can cause the water supply to be rejected and replaced with alternative (potentially lower-quality) sources, and they are simple and affordable to qualitatively evaluate in the field. Physical parameters for water include pH, TDS, salinity, and hardness. Chemical quality determines physical quality.

The appearance, taste, odor, and feel of water influence what people experience when they drink or use it, as well as how they rate its quality; other physical characteristics can indicate whether corrosion and encrustation are likely to be significant issues in pipes or fittings. The measurable characteristics that determine these largely subjective qualities are: true color (i.e., the color that remains after any suspended particles have been removed), turbidity (the cloudiness caused by fine suspended matter in the water), hardness (the reduced ability to lather using soap), total dissolved solids (TDS), pH, temperature, taste, odor, and dissolved oxygen (ADWG, 2006).

2.8.2. Chemical aspect

Chemical pollution of water sources can occur as a result of industrial and agricultural practices, municipal solid waste, urban runoff, or natural causes. Toxic substances in drinking water have the potential to produce acute or long-term health damage. After prolonged exposure to contaminants in drinking water for years rather than months, they constitute a health hazard (WHO, 2006). Chemical levels in drinking water are rarely high enough to induce acute health consequences; hence chronic health problems are more likely. There are numerous evidences that chemical pollutants caused harmful human health concerns in urban watersheds (EPA, 2010).

2.8.3. Biological aspects

Water naturally supports a vast community of living organisms, including aquatic plants, animals, algae, bacteria, parasites, and viruses. Some of these organisms are innocuous, while others may be hazardous to people. Those of greatest importance to us are pathogens, or disease-causing organisms. These diseases are sometimes referred to as microorganisms, microbes, or bugs, depending on the language and location.

In the 21st century, polluted water is the world's second leading cause of child death. Every year, around 1.5 million people die as a result of diarrhea and other diseases caused by contaminated water and inadequate sanitation. Nearly half of all individuals in underdeveloped nations suffer at any given moment from a health condition caused by water and sanitation shortages (UNDP, 2006).

The WHO Guidelines for Drinking Water Quality state that infectious diseases caused by pathogenic bacteria, viruses, protozoa, and helminthes are common in drinking water and have far-reaching health consequences. Although there are various contaminants in water that may be detrimental to people, the primary goal is to guarantee that drinking water is free of disease-causing microbes (WHO, 2006). Drinking water should be devoid of any pathogenic microorganisms. It should also not contain bacteria that would suggest excremental pollution; the key sign of which being coliform bacteria found in the feces of warm-blooded animals (Maher, et al 1997).

The microbiological quality of drinking water is managed by utilizing certain treatment techniques, and the presence of coliform bacteria is checked. Chlorine is the standard disinfectant since it is easily accessible and affordable (Mark et al, 2005).

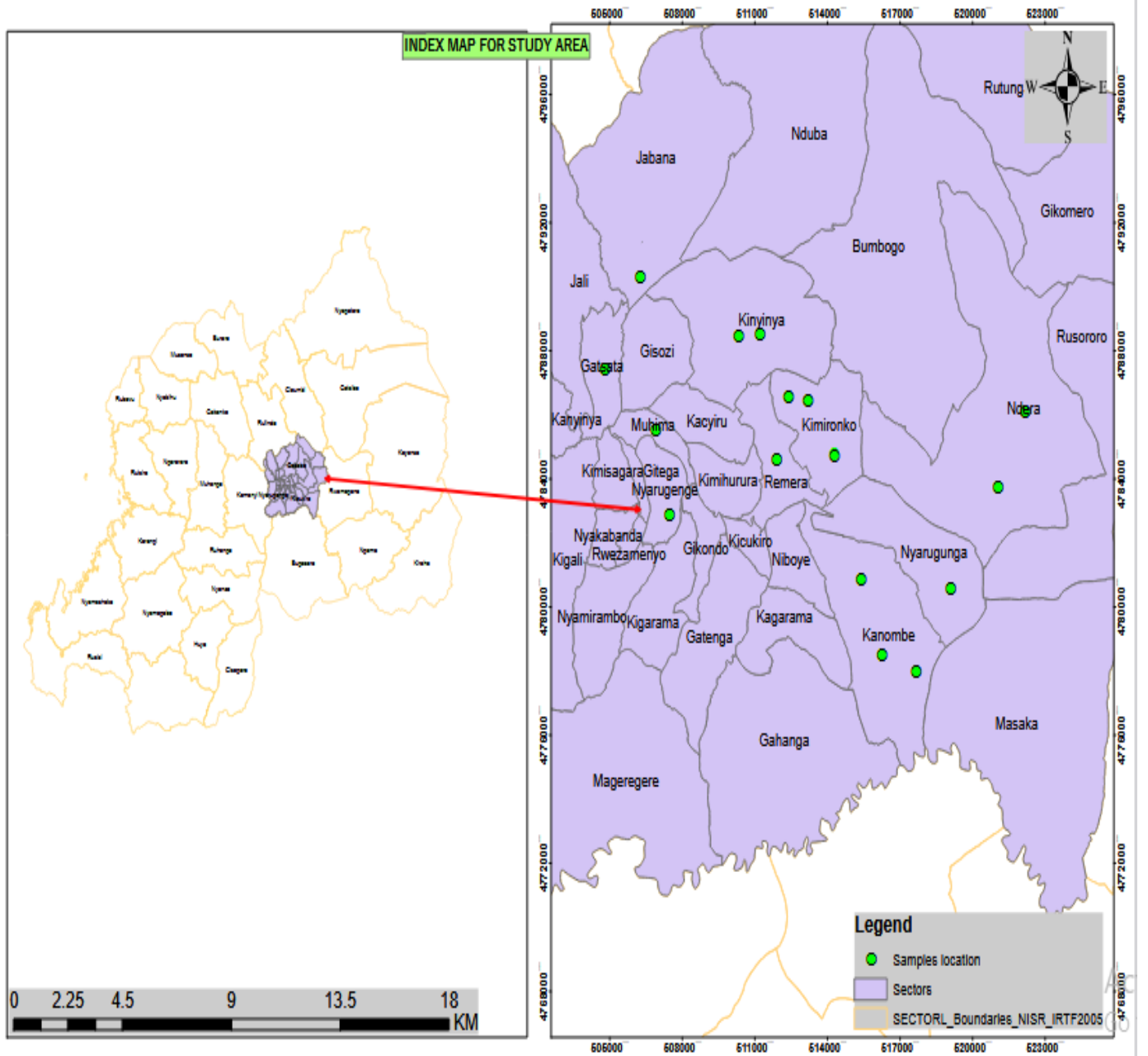
CHAPTER3: MATERIALS AND METHOD

3.1. Description of the Study Area

The City of Kigali is the capital of Rwanda and is located at Rwanda's geographical heart. Occupying an area of 730km², the City is located at latitude 10°58' S and a longitude 30°07' E. The average annual precipitation rate is approximately 950mm, with an annual average high temperature of 27°C and annual average low temperature of 16°C.

The City of Kigali is composed of three Districts namely Gasabo, Kicukiro and Nyarugenge. Gasabo is the largest district by geographical area at 429.3km², followed by Kicukiro 166.7km² and Nyarugenge 134km². The City of Kigali population is 1,745,555 the data source is the fifth Rwanda Population and Housing Census (RPHC5).The districts are also divided into 35 administrative sectors which in turn are divided into 161 Cells. The smallest administrative unit is the village and the City is made up of 1,155 villages. The City borders the Gicumbi and Rulindo Districts of Northern Province, Bugesera and Rwamagana Districts of Eastern Province and Kamonyi District of Southern Province.

STUDY AREA



3.2. Social economic structure

3.2.1. Demography.

The City of Kigali, the capital city of Rwanda has seen rapid growth for the last two and half decades. It is among the fastest growing cities in Africa with an urbanization annual growth rate of 4% and it contributes over 41% of the national GDP which indicates the primacy of Kigali to the Rwandan economy. The 5th Rwanda Population and Housing Census (PHC5) found 1,745,555 residents in Kigali, representing 13.17% of the country's total population of 13,246,394. The city's population is predominantly male, with 888,882 men making up 50.9% of the total. In 2022, Kicukiro district had 491,731 residents, accounting for 28.2% of the total population of Kigali City. Nyarugenge, with 374,319 residents, is the least populated district in Kigali City, accounting for 21.4% of the total population.

Table3.1: urban water subscribers per province and City of Kigali

Province/Districts	counts			Population share(% of the total population)	Population density
	Both sexes	male	Female		
				Both sexes	503
Rwanda	13,246,394	6,429,326	6,817,068	100	
City of Kigali	1,745,555	888,882	856,673	13.2	2,401
Nyarugenge	374,319	195,780	178,539	2.8	2,830
Gasabo	879,505	443,987	435,518	6.6	2,056
Kicukiro	491,731	249,115	242,616	3.7	2,944

Source: national institute of statistics of Rwanda (nistr)

3.2.2. Information about the household of Kigali

According to the 5th RPHC 2022 results, Rwanda has 3,312,743 private households, with 448,868 in Kigali City and 135,463 in Kicukiro District. Kicukiro district's average household size is 3.6 people. There are 103,985 in Nyarugenge District. The average household size in Nyarugenge District is 3.5 people per household. There are 249,420 in Gasabo District. The average household size in Gasabo District is 3.5 people per house.

Table 3.2: Family sizes per household

Sectors	Number of private households	Corresponding population	Average household size
Rwanda	3,312,743	13,100,600	4.0
City of Kigali	488,868	1,720,477	3.5

Source: 5th RPHC 2022

3.3. Materials.

3.3.1. Source of data

The data was collected from both primary and secondary sources. The primary data for the study were obtained through water meter readings, Survey Questions, discussions with water utility staff members to obtain additional relevant information on the subject and laboratory experiment while the Secondary data were gathered from various literature reviews, design reports, the town water supply service office's existing documents, and annual report papers.

3.3.2. Equipment

Phone calls and emails were used to communicate with customers, stakeholders, and water supply service providers. Notebooks and cameras were used to document observations and visual evidence of water supply issues.

The water quality parameters were analyzed using the equipment/instruments listed below.

PH meter: was used to measure PH

TDS meter: was used to measure TDS

Turbid meter: was used to measure turbid

Spectrophotometer: A device was used to measure various ions

DO Meter: A device was used to measure the dissolved oxygen content in the samples.

Wash bottle: was used for rinsing and cleaning various apparatus.

Conical flask: A flask with a conical shape used for mixing and holding liquids during the experiment.

Measuring cylinder: was used for precise measurement of liquid volumes.

Pipette with elongated tip: A pipette with a longer tip to accurately transfer small volumes of liquid.

Gloves and seal starch: Personal protective equipment used to ensure safety during the experiment and seal starch for securing airtight conditions.

3.4. Methods

3.4.1. Selection of Sample Study Area

Although the area to be studied is a subsystem, this research considers the entire area and uses random sampling to select samples.

3.4.2. Data collection

Primary Data collection.

Data collection is the most important part of research work. To complete this work, data on the necessary parameters for examining water quality were collected. The data collection techniques included conducting a field visit, questionnaire and collecting data.

Secondary data collection

Data on water production and consumption were obtained from the town water supply office. Design reports from previous consulting offices were used as secondary data in this study. The summarized collected data are presented as follows:

3.4.3. Sampling procedures

In the group stage, cluster sampling techniques were employed, along with a methodical approach to sampling in order to locate the houses. To choose each respondent individually, to prevent gender bias, the household will be given permission for an incidental interview. To reduce the possibility of systematic biases resulting from the use of this specific sampling technique, a convenient sample of households will be selected from consumers linked to the Kigali water network (KWN) distribution system.

Interviews were also conducted with a few Commercial and Institutional service category groups that failed in any of the communities. The areas were purposefully chosen because they were strategically located in the town's center and have been characteristics that would be important

for the study. The individual households for the questionnaire distribution were chosen using the simple random sampling techniques.

3.4.4. Sample size

To ensure a representative sample, we referred to the literature review to determine the places that were confronted with water challenges, and this study focused on the following regions in Kigali: Ndera, Kanombe, Biryogo, Gasyata, Kimisagara, Kagugu, Zindiro, Busanza as shown in table 3.3. Interviewing everyone would have been difficult, thus we have chosen questionnaires that was delivered randomly to 320 chosen families using simple random sampling method.

Table 3.3: Areas and Numbers of Questionnaires Administered

AREAS	Number of questionnaires
NDERA	40
NYARUGUNGA(KANOMBE)	40
GASYATA	40
BIRYOGO	40
KIMISAGARA	40
KAGUGU	40
ZINDIRO	40
BUSANZA	40
Total	320

3.5. Assessment of water quality.

Samples collected from the house connection were taken to the UR-CST Laboratory, where the physical, chemical, and biological properties of the water were examined. The parameters examined to laboratory are summarized in tables below.

Table3.4. Physical requirement

SI.No	characteristics	Treated potable water	Method of test
2	Turbidity(NTU max)	≤5	ISO 7027
3	Taste	Not objectionable	-
4	Odour	odourless	-
5	Conductivity(μS/cm) max	1500	ISO 7888

Source: : RWANDA STANDARD RS EAS 12: 2014, Second edition

Table3.5. Chemical requirement

SI.No	Characteristics	Treated potable water (mg/L max.) Required standards	Method of test
1	Total dissolved solids	700	ASTM D 5907
	Turbidity	≤5NTU	ISO 7027
2	Total hardness as CaCO ₃	300	ISO 6059
	manganese	0.1	ISO 6333
4	Chloride as Cl ⁻	250	ISO 9297
5	PH	6.5-8.5	ISO 10523
5	Total Iron as Fe	0.3	ISO 6332
7	Sulphate as SO ₄	400	ISO 22743
9	Magnesium as Mg ^{**}	100	ISO 7980
10	Calcium as Ca ^{**}	150	ISO 7980
11	Nitrates as NO ₃ ⁻	45	ISO 7890
12	Phosphate	2.2	ISO 15681
13	fluorides	1.5	ISO 10359
14	Residual free chloride	0.2-0.5	ISO 7393

Source: RWANDA STANDARD RS EAS 12: 2014, Second edition

Table 3.6. Biological requirement

S. No	characteristics	Required standards	Method of test
1	Total coliforms	Absent	ISO 9308-1
2	E-coli	Absent	ISO 9308-1

3.5.1: Sampling

Water samples were taken from several taps of water utilized by residents in Kigali. A total of fifteen water samples were collected for laboratory analysis, twelve from household connections and three from the food commercial centers. The sample distance between samples is at of one cell to another and/or one sector to another. Each sample is coded as Kigali tap S1, to Kigali tap S15. The standard test method is adopted. The Sample and description is described below. The test method is International Standards guidelines.

Table 3.7. Sample sources.

Sample code	Location	Source Supply(WTP)
Kigali tap S1	Ndera	Karenge
Kigali tap S2	Ndera	Karenge
Kigali tap S3	Kanombe	Karenge
Kigali tap S4	Kanombe	Karenge
Kigali tap S5	Economic zone	Karenge
Kigali tap S6	biryogo	Kimisagara
Kigali tap S7	Muhima	Kimisagara
Kigali tap S8	Gasyata	Kimisagara
Kigali tap S9	Kimironko	Kanzenze
Kigali tap S10	Kimironko	Kanzenze
Kigali tap S11	Busanza	Kanzenze
Kigali tap S12	Karuruma	Nzove
Kigali tap S13	Kagugu	Nzove
Kigali tap S14	Remera	Nzove
Kigali tap S15	Kibagabaga	Nzove

3.5.2. Laboratory of Experiments

All analyses will be carried out in compliance with Standard Methods and within permitted holding times as per Standard Methods. The physical and chemical parameters of water quality will be measured. The analysis will focus on key physical, chemical, and biological parameters to evaluate the suitability of the water for drinking purposes.

3.5.3. Parameters and Method used

Ca+Mg(Hardness):EDTA Titrimetric Method .

Principles

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

Reagent

a) Buffer: 1. Dissolved 1.179g $\text{Na}_2\text{ADTA}\cdot 2\text{H}_2\text{O}$ and 780mg $\text{MgSO}_4\cdot 7\text{H}_2\text{O}$ in 50 ml

2. Dissolved 16.9g NH_4Cl in 143 Conc. NH_4OH

Add solution 1 to solution 2 with mixing and dilute to 250ml

b) Eriochrome black T: Dissolve 0.5g in 90ml of triethanolamine.

c) EDTA 0.01M: Dissolve 3.723g $\text{Na}_2\text{EDTA}\cdot 2\text{H}_2\text{O}$ in 1000ml. standardize this solution 1mmol EDTA= 1mmol Ca

Procedures.

1. Take a sample volume that required less 15ml EDTA and complete titration in 5min measured from time of buffer addition. Dilute 25ml sample to 50 ml in borosilicate Erlenmeyer.

2. Add 1-2 buffer, Usually 1ml will be sufficient to produce a PH 10.0 ± 0.1
3. Add 2 drops Eriochrome black T Indicator
4. Titrate slowly with EDTA with continuous stirring; until the last reddish tinge disappears add the last drops at 3-5 Sec intervals.

Calculation

Hardness as Mg CaCO_3 / L = $(V \cdot M \cdot 100) \cdot (1000/\text{ml sample})$ where

V= ml EDTA Titrated

M= Morality of EDTA

TMg=(THa - TCa)

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

Fe²⁺ phenanthroline Method

Principle

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

Apparatus

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

Reagent

The hydroxylamine ,phenanthroline and stock iron solution

Cl⁻ -Argenometric Method.

Principles.

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

Apparatus:

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

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

Procedure.

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

Calculation

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

A=ml titration for sample

B=ml titration of blank

M= Molarity of AgNO₃

NO₃⁻ Spectrophotometric Method with 2, 6 dimethyl phenol

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

Reagents:

1. Dissolve 0.040g amino sulfonic acid in 10ml H₂O Transfer to 2L Beaker and add 500ml conc. H₂SO₄ and 500ml conc. H₃PO₄
2. Dissolve 1.2g 2,6 dimethyl phenol in 1000ml glacial acetic acid
3. Stock NO₃-N 1000mg/L: Dissolve 7.218g KNO₃(Dried at 105°C for 24h) into H₂O And dilute to 1000ml
4. Standard NO₃-N 100mg/L :Dilute 10.00 ml stock solution to 100ml with 100ml

Calibration.

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

Procedure.

-To 50ml clear sample add 1ml 1M HCl and mix

-proceed as mentioned under calibration $\text{mgNO}_3\text{-N/L} = (\mu\text{g NO}_3\text{-N IN 50 mL 3rd volume}) / (\text{ml sample})$

PO₄³⁻ Ascorbic acid spectrophotometric Method.

Principles

Ammoniummolybdate and potassium antimonyl tartrate react in acid medium with orthophosphate to form a phosphomolybdic acid that is reduced to intensely colored molybdenum blue by ascorbic acid. The minimum detectable concentration is $10\mu\text{g P/L}$ with use of a 5cm cell. Phosphates that respond to colorimetric test without any treatment like hydrolysis and oxidation (except filtration) are also called dissolved reactive phosphorus (DRP).this reactive P is largely a measure of orthophosphate.

Apparatus.

1. Spectrophotometer for use at 880nm with 1cm cell.
2. Acid-washed glassware: phosphate contamination is common because of its absorption on glass surface.

Reagent.

- a) H_2SO_4 2.5M: Add 70 mL conc. H_2SO_4 to 420mL H_2O
 - a. Potassium antimonyl tartrate: Dissolve $1.3715\text{gK(sbo)C}_4\text{H}_4\text{O}_6.1/2\text{H}_2\text{O}$ in 400ml H_2O and dilute to 500mL in volumetric flask. Store in glass stoppered bottle.
 - b. Ammonium heptamolybdate: Dissolve 20g $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}4\text{H}_2\text{O}$ in 500mL in H_2O Store in glass stoppered bottle.
 - c. Ascorbic acid 0.1M: Dissolve 1.76g ascorbic acid in 100mL H_2O .This solution is stable for about 1 week at 4°c .

Procedures.

-Pipette 50.00 mL 0.45 μm sample to 100mL volumetric flask, add 1 drop phenolphthalein indicator.

-if red color develop ($\text{PH}>8.3$) add dropwise 2.5M H_2SO_4 to just discharge the color

-Add 16mL combined reagent, fill up to the mark and mix

-Measure the absorbance at 880nm between 10-13 min with a 1cm cell

$\text{mg P/L} = (\mu\text{gP in } 100\text{mL endvolume})/(\text{mL sample}).$

SO₄²⁻ spectrophotometric Method.

Principles

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

Apparatus

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

Reagent

- a) Buffer: Dissolve 30g MgCl₂·6H₂O, 5g CH₃COONa·3H₂O, 1g KNO₃ and 20mL CH₃COOH in 500mL H₂O and make up to 1000mL. use this buffer for sample containing >10mg SO₄²⁻/L.
- b) BaCl₂ crystal of 20-30mesh(0.6-0.8mm)
- c) Stock SO₄²⁻: Dissolve 1,479g dried Na₂SO₄ in 1000mL 1mL=1mgSO₄²⁻
- d) Standard SO₄²⁻: Dilute 100mL stock to 1000mL 1.00mL =100μg SO₄²⁻

Procedure for SO₄²⁻ Concentration between 10-40mg/L

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

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

3.6. Water demand data

To estimate the current water demand in the distribution network, the following steps were required:

Assigning the overall population of the town

Population is the most important data for determining water demand in the distribution network. Facts show that there are various population forecasting methods used for estimating the current or future population of a given town, but the results differ from one another due to the parameters of each method. To predict the population of a town, it is necessary to understand the factors influencing population distribution, size, and growth rate. Migration is one of the most important factors influencing population change in Kigali. For this study, historical figures are used, assumptions are made (data is available), and the 2022 Kigali city population figure is used, along with population growth rate, for population projection methods. Finally, the town's population figure was assessed in 2024.

Population forecasting.

Exponential population forecasting method is used to forecast the current Kigali city population.

$$P=P_0*e^{rn} \dots\dots\dots (3.1)$$

Where:

P = Estimated population

Po = base population.

r = Growth rate

n = Number of year

Table 3.8: Population growth projection

Description	unit	2002	2012	2022	2023	2024	2030	2042
Average growth rate	%	2.6	3	3.69	4	4	4	4
Population		596,000	1,135,428	1,745,555	1,816,792	1,890,937	2,403,852	3,884,804

Assigning average day water demand of Kigali city

To determine the town's average water demand, a deterministic water demand estimation method was used. As a result, the per capita water consumption of the town was calculated using the annual water consumption recorded data and the projected total population figure for 2022. The equation below was then used to assess.

$$\text{Per capital consumption} = \text{Annual consumption (m}^3 \cdot 1000\text{l/m}^3) / \text{total population} \cdot 365 \dots (3.2)$$

As a result, the average water demand for the town was calculated by multiplying the per capita demand by the estimated population, as shown below.

$$Q_{ave} = \text{Per capital water consumption} \cdot \text{total population} \dots (3.3)$$

3.7. Assessment of customer satisfaction.

The assessment for the customer satisfaction evaluation was done through questionnaire and interview. The questionnaire were prepared and distributed to the population in the town and the output is analyzed. The random sampling was used to distribute the questionnaires but the total subsystem area was considered and the Excel chart was used to analyze the questionnaires.

CHAPTER 4: RUSULTS AND DISCUSION

This chapter discusses the analysis and interpretation of data obtained through field research, site visits, and personal observation for the study. This chapter provides information to inform discussions and interpretations.

4.1. Estimated water demand.

Estimating the town's expected water demand was used to evaluate and size system components such as pumping stations, reservoirs, and transmission and distribution pipelines.

4.1.1. Populations forecasting.

The water demand of a particular town is proportional to the population to be served. The population of Kigali city from the National Institute of Statistics of Rwanda report in 2022 was 1745555, which was used as the base population for the current estimate. According to kigilicity.gov.rw, the annual growth rate for Kigali's population is at 4%.

Table 4.1. Population growth projected Kigali city.

Description	unit	2002	2012	2022	2023	2024	2030	2042
Average growth rate	%	2.6	3	3.69	4	4	4	4
Population		596,000	1,135,428	1,745,555	1,816,792	1,890,937	2,403,852	3,884,804

Using the exponential population forecasting method, Kigali's total population is estimated to be 1,745,555 in 2022

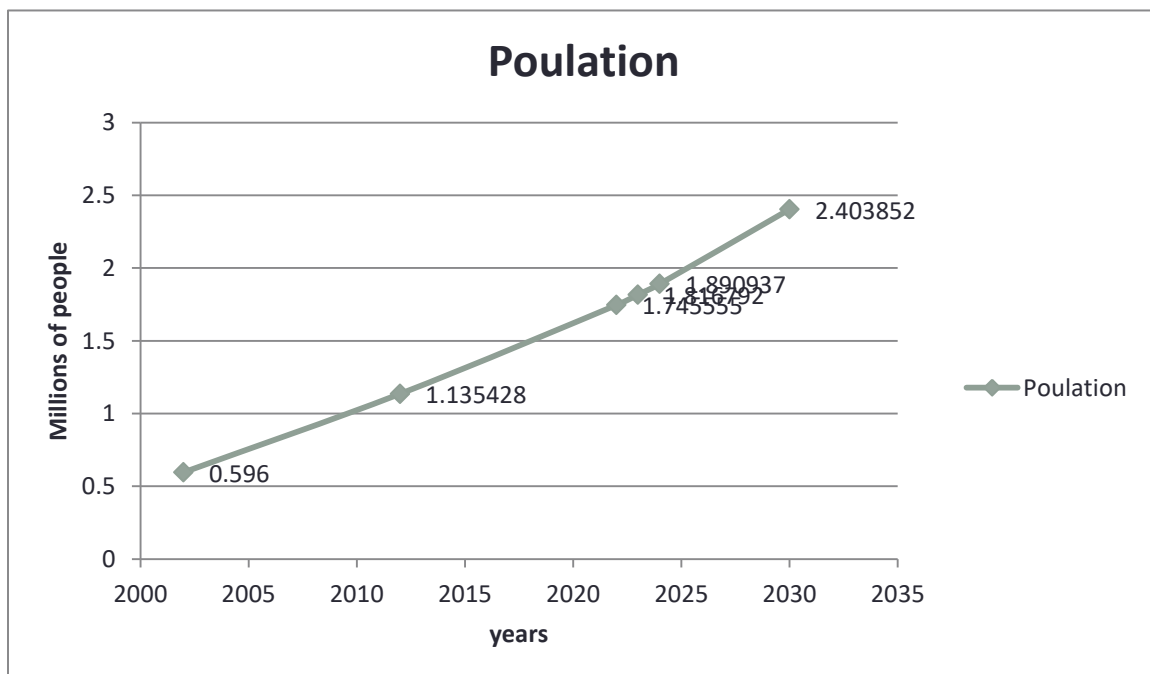


Figure 4.1. Population growth of Kigali from 2002

4.1.2. Per capita water consumption.

The per-capita water consumption for various demand categories varies with the town's size and level of development. In Kigali city, there was a high demand for water due to the growth of socioeconomic activity in both the governmental and private sectors. The data from Rwanda utilities Regulatory Authority (RURA) on water statistics report showed that in 2023, the quantity of water billed in Kigali city was 75,169,597 L/therefore the quantity of water supplied was 120,476,413 L/d so that the differences of 35% is water loss.

This means the total quantity water consumed in Kigali city in 2023 was 75,169,597 L/d. based on the annual water consumption and population in 2023. The average per capita consumption in Kigali was calculated to be 41 liters per day (41 l/c/d). According to the World Health Organization categorized households consuming less than 20litre/capita/day (LPCD) as 'basic access', those consuming 50 LPCD as 'intermediate. However, research indicates that 50 liters per capita per day is the quantity of safe water required to realize essential levels for health and hygiene. Therefore, Kigali water consumption is lower than 50 l/p/d resulting showed that Kigali has water shortage.

4.1.3. Kigali city water demand.

Several mathematical methods exist for estimating a town's water demands, including extrapolating historical trends and correlating demand with socioeconomic variables. However, the most common method of forecasting future water demand is estimating current per capita water need and multiplying this by the projected population. Water demand in Kigali city is predicted to be 375,300,325l/d (375,300.325m³) in 2022, **390,612,280 l/d (390,612.280m³)** in 2023and 406,551,455l/d (406,551.455m³) in 2024. This was calculated by multiplying the population by the water needs (l/p/d). Tables 4.2 and 4.3 illustrate water demand in 2022 and 2024, respectively. Projecting Kigali water consumption became necessary due to the City growing population and economic activity.

As a City grow in population, commercial centers, and institutions, water demand rises. However, Kigali's Water treatment plant (WTP) capacity decreases due to depreciation of facilities over time. By assuming no leakage losses the Kigali water supply system produced 120,476,413 L/d (66l/d/p) in 2023 which falls short of the initial water demand of population of Kigali city. Referring to this result the study found that Kigali water supply system is not reliable to meets the demand of homes and businesses on a daily basis.

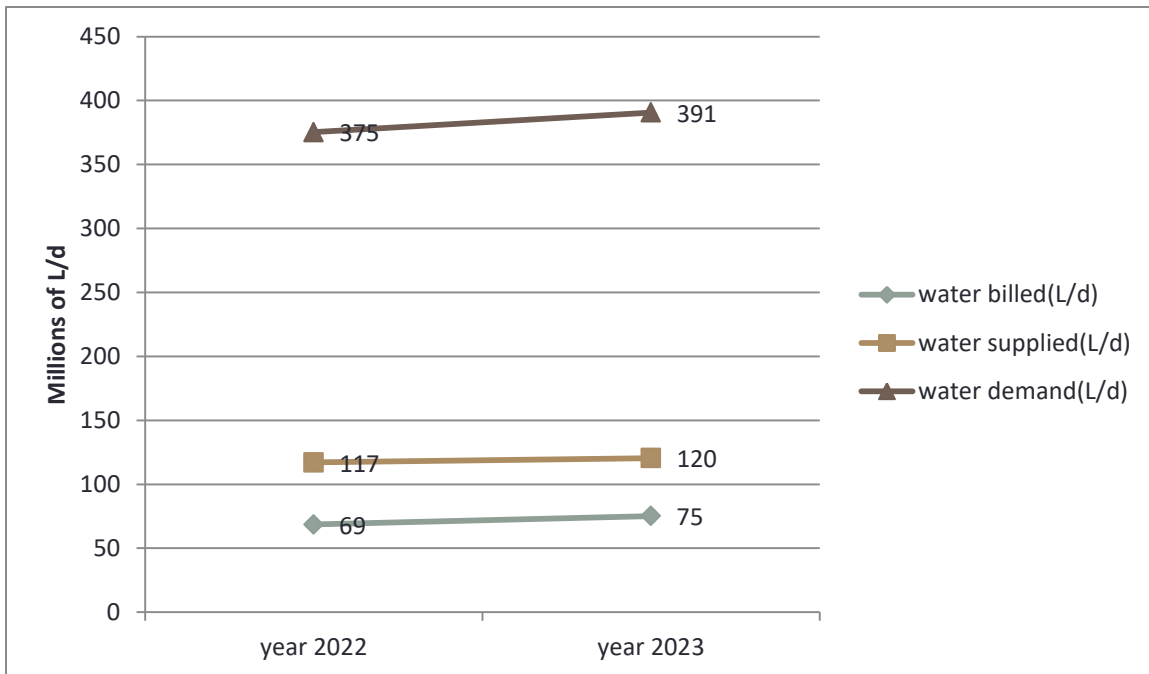


Figure 4.2.Kigali water demand

4.1.4. Measures for Kigali City's water demand

Several measures should be taken in order to better control water demand and enhance the effectiveness of Kigali City's water supply services. These include:

1. Encourage the conservation of water

Campaigns for Public Awareness: Inform locals and companies on the value of water conservation through public relations campaigns, neighborhood forums, and educational initiatives.

Water-Sparing Appliances: Promote or require the use of water-efficient fixtures in residences, workplaces, and public spaces, such as low-flow toilets and faucets.

Rewards for Water-Sparing Behaviors: Provide consumers that use water-saving technologies or cut back on their water usage with incentives like refunds or discounts.

2. Put Water Demand Management Techniques into Practice

Water Audits: To find inefficiencies and suggest solutions, conduct water audits for major users such as hotels, government buildings, and industry.

Tiered Pricing: To incentivize customers to use less water, implement a tiered pricing structure wherein water charges rise as consumption levels rise.

Establish programs for the detection and repair of leaks in private plumbing systems as well as the public distribution system to cut down on water waste.

3. Expand and Improve Infrastructure

Boost Storage Capacity: Construct more reservoirs and water storage facilities to handle periods of high demand and protect against shortages .

Increase the Distribution Network: To relieve pressure on the current infrastructure, extend the water supply network to include underserved areas.

Rehabilitate Aging Infrastructure: To minimize water loss and provide a more dependable supply, modernize outdated and ineffective pipelines and distribution systems.

4. Provide Other Sources of Water

Rainwater Harvesting: Promote the use of rainwater harvesting systems in the commercial, industrial, and residential sectors for non-potable applications.

Reuse and recycle: To lessen the pressure on fresh water sources, encourage the use of treated wastewater for industrial activities, landscaping, and irrigation.

Investigation and Development of Alternative Water Sources: Look into and develop other sources, such as surface water from surrounding rivers, groundwater, and, if practical, desalination.

5. Reinforce the Framework for Policies and Regulations

Water Use Regulations: Implement laws that restrict the amount of water used during times of scarcity, such as prohibitions on the use of water for non-essential purposes (such as washing vehicles and watering lawns) .

Building codes: Revise them to mandate water-efficient designs and technology for both new and renovated buildings.

Implement integrated water resource management (IWRM) techniques to synchronize land, water, and related resource development and management across sectors.

6. Water Management Driven by Data

Installing smart water meters can help utilities and consumers monitor and control use more successfully by giving real-time data on water usage .

Demand Forecasting: Based on population growth, economic activity, and patterns in climate change, anticipates future water demand using sophisticated data analytics and modeling.

Water Usage Monitoring: Keep an eye out for trends in water usage and modify your supply and demand plans as necessary to minimize the chance of shortages.

7. Promote Water-Efficient Farming

Effective Irrigation Systems: Encourage peri-urban agriculture to employ drip irrigation and other water-efficient irrigation methods.

Water-Smart Crops: Promote the growth of crops that are more adapted to the local climate or that demand less water.

8. Participation and Engagement in the Community

Involve Local Communities: Encourage local communities to take part in water conservation efforts and involve them in decisions about water management.

Mechanisms for collecting feedback: Provide forums where locals can discuss problems related to water demand and offer solutions.

9. Being Ready for the Effects of Climate Change

Invest in climate-resilient infrastructure to protect it from the effects of climate change, such as protracted droughts and heavy rainstorms.

Plans for Emergency Water Supply: Create and maintain emergency plans for water supply on a regular basis to make sure that demand can be satisfied even in difficult circumstances.

By putting these strategies into practice, Kigali City will be able to better control water demand and guarantee a steady and sustainable supply of water for its citizens and businesses.

4.2. Customer Satisfaction Analysis.

4.2.1. Demographic data

Out of 320 valid respondents for the question about gender and Age the Figure 4.3 from Appendix (Table4.A) shows that 69.1% of respondents were under 30 years old, 86.81% were between 30 and 45 years old, and 44.1% were over 45. Because the respondents in Kigali Municipality were adults, their perspectives on water service delivery can be considered accurate. Overall, there were as many men as women.

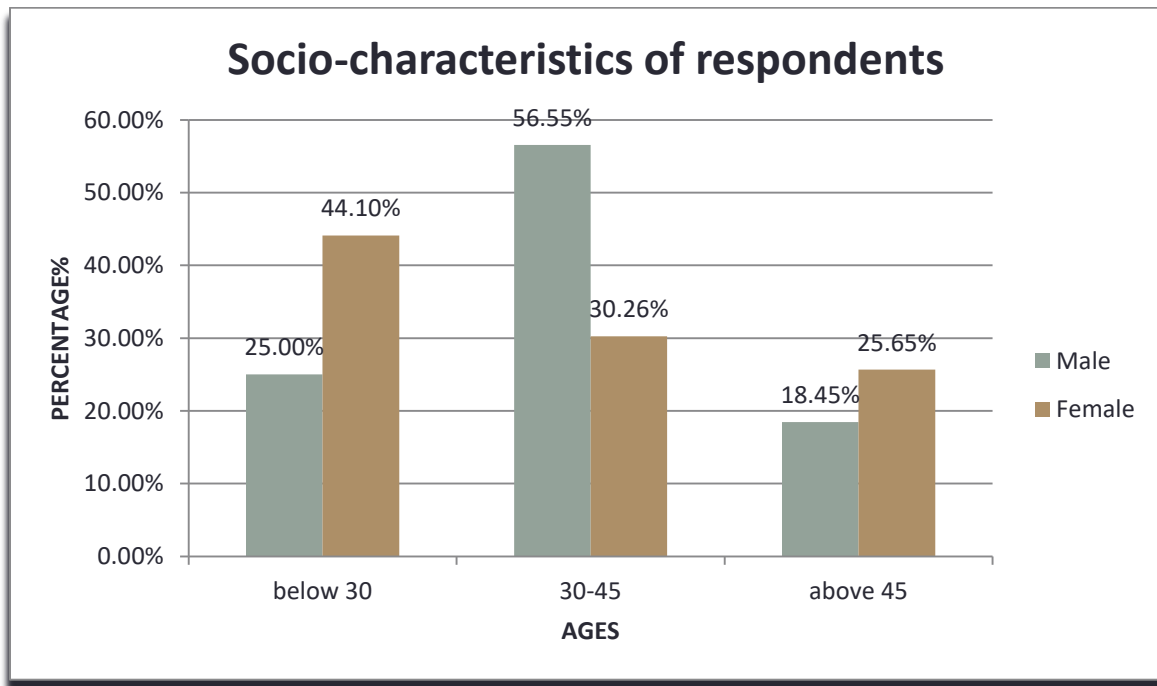


Figure 4.3. Gender and Age distribution respondent.

4.2.2. Educational level of Respondents

Out of 320 valid respondents for the question about Education level the Figure 4.4 (Appendix A, Table 4.B) shows that 25.00% of respondents had university education, 54.06% had secondary education, 19.38% had primary education, and 1.56% had no formal education. The majority of respondents (98.44%) had education that helped them understand the questions and provide informed responses.

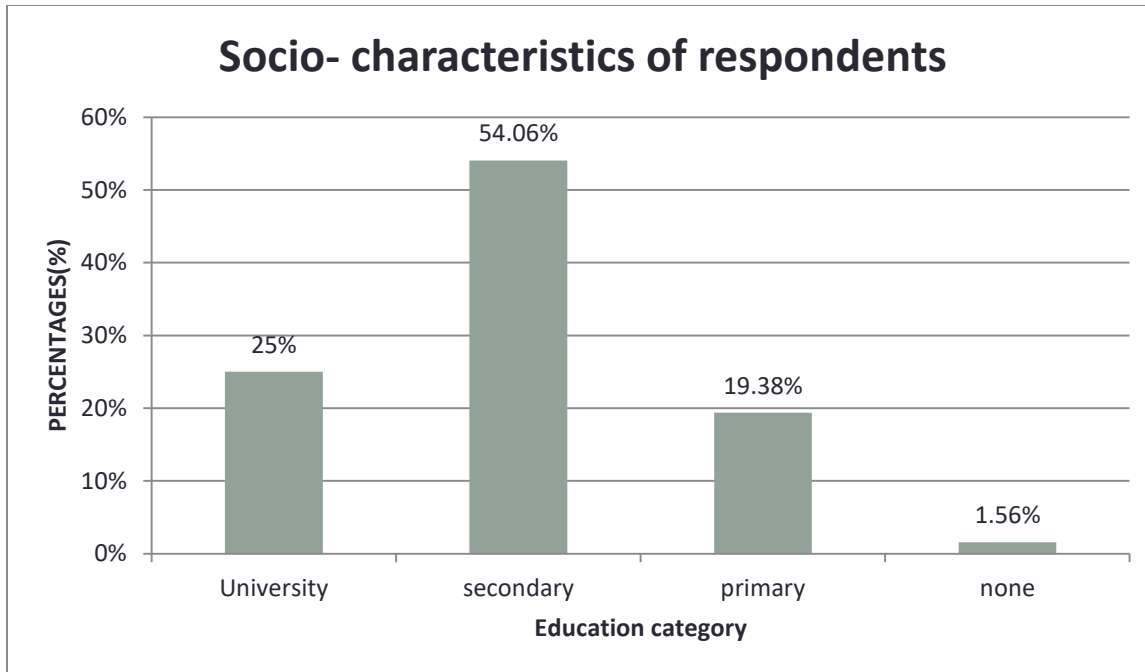


Figure 4.4. Educational level of respondents

4.2.3. Flow Condition

Household Size

The researcher wanted to know how many people lived in a residence to estimate their water consumption and out of 306 valid respondents for the question of “How many are you in your household?” Table 4.4 reveals that the most common household size was 4 to 7 (**50%**), followed by 8 to 10 (**22.86%**), and more than 10 (**16.34%**). Most homes with one to three (**10.80%**) were found in the below-average income community.

Table 4.4. Family size

Household size	1-3	%	4-7	%	8-10	%	Above 10	%
NDERA	6	16.22	19	51.35	10	27.03	2	5.40
NYARUGUNGA	4	10	22	59.46	6	15	5	13.51
GASYATA	7	17.5	14	35	10	25	9	22.5
BIRYOGO	3	7.5	22	55	7	17.5	8	20
KIMISAGARA	3	8.57	16	45.71	10	28.57	6	17.14
KAGUGU	4	10	20	50	8	20	8	20
ZINDIRO	2	5	23	57.5	8	20	7	17.5
BUSANZA	4	10.81	17	45.95	11	29.73	5	13.51
Total	33	10.80	153	50	70	22.86	50	16.34

Consumer Feedback on Water Flow Condition.

Water flow was assessed throughout three time periods: dawn (0-8 GMT), afternoon (8-16 GMT), and night (16-24 GMT) and out of 320 valid respondents for the question of “How many hours a day do you get water?” the Figure 4.5 (Appendix A; Plotted from Table 4.C) shows that **30.31%** of respondents received water supply at dawn (0 - 8 hours) in a day, 36.25% received water supply between 8 - 16 hours, and 33.44% received water supply between 16 - 24 hours. The intermittent flow of water could be attributable to demand surpassing supply, which necessitates water rationing.

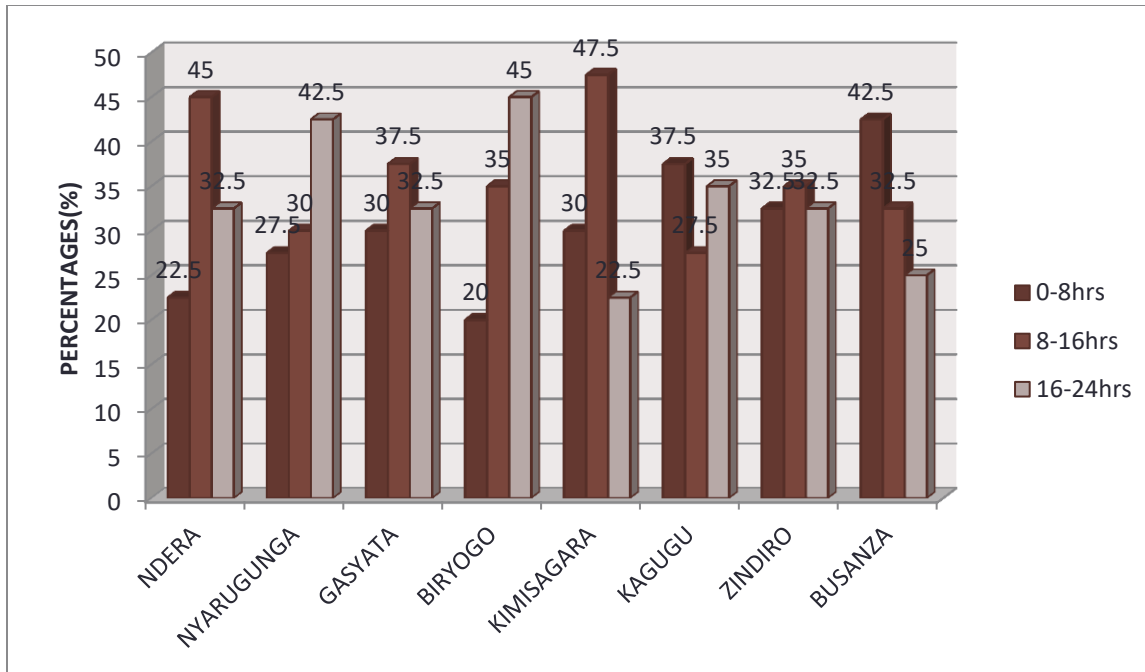


Figure 4.5. Hours of flow in a day

4.2.4. Customer perception of the quality of water.

Figures 4.6, 4.7, and 4.8 show physical water quality criteria (taste, smell, and color) based on Tables 4.D, 4.E, and 4.F (see Appendix). The researcher utilized a four-point grading system ("Excellent", "Good", "Fair", and "Poor") to assess the physical quality of water. Respondents were asked to select the most accurate description of their impression of water quality and Out of 280 valid respondents for the question of "What are your thoughts on the physical and taste quality of the water?" The study found that customers were largely satisfied with the taste of water (35.71 % rated it as fair, 15% as excellent, 45% as good, and 4.29% as poor)

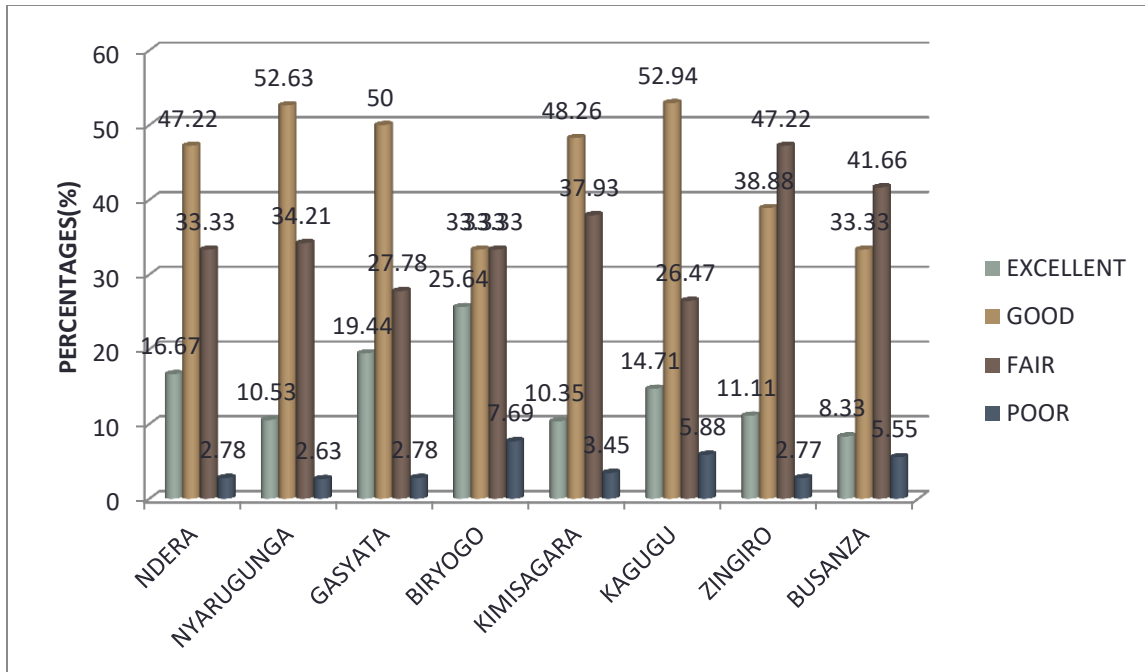


Figure 4.6. Consumer Perceptions on the Taste of Water

Out of 320 valid respondents for the question of “What are your thoughts on the physical water quality – smell?” The study found that customers usually liked the smell of water. Figure 4.7 shows that 14.688% evaluated it as excellent, 47.8125% as good, and 33.125% and 4.375% as fair and poor, respectively.

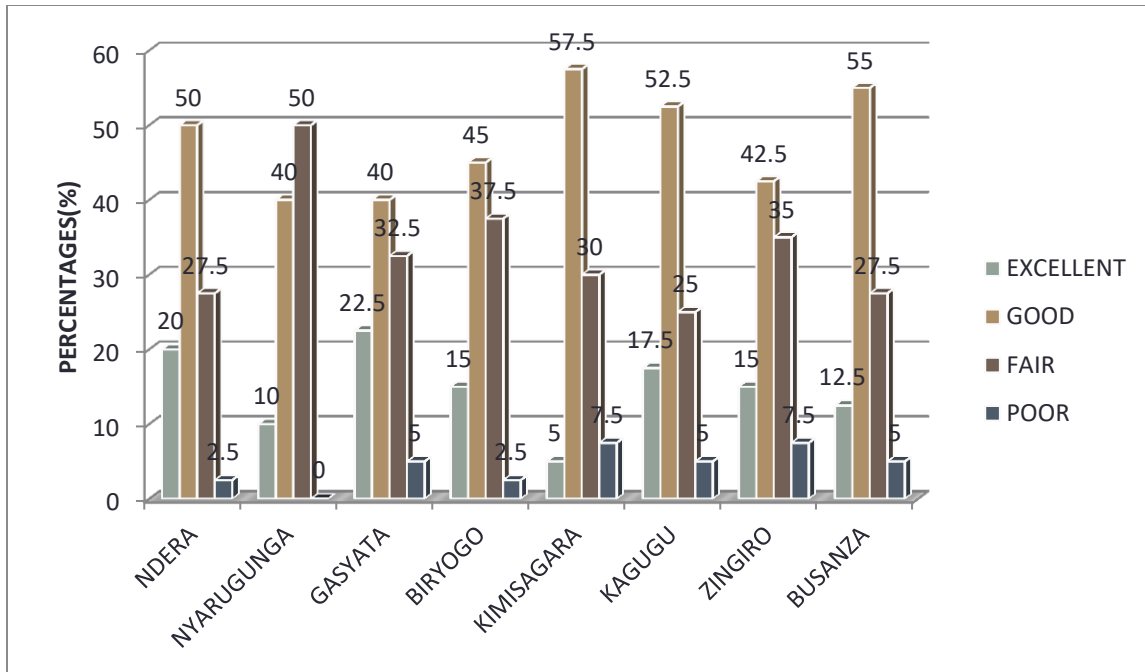


Figure 4.7. : Consumer Perceptions on the Smell of Water

Finally out of 320 valid respondents for the question of "What are your thoughts on the physical water quality – color and according to Figure 4.8, the majority of customers were dissatisfied with the color of Water as (5.9375%, 51.25%, 39.375%, and 3.4375%) Excellent, Good, Fair, and poor respectively. This important characteristic had a detrimental impact on customers. Perception refers to the overall impression of the physical quality of the water provided to them. The investigation found that the water color was considerably affected after any kind of service interruption. Also, the tint of the water appeared brownish with instances were little Particles were found in the water, prompting most users to store it. Prior to use, settle. As a result, overall satisfaction with the physical quality of water was low. Possible causes include unattended leaks in some regions, resulting in bad water entering the water supply system under vacuum conditions.

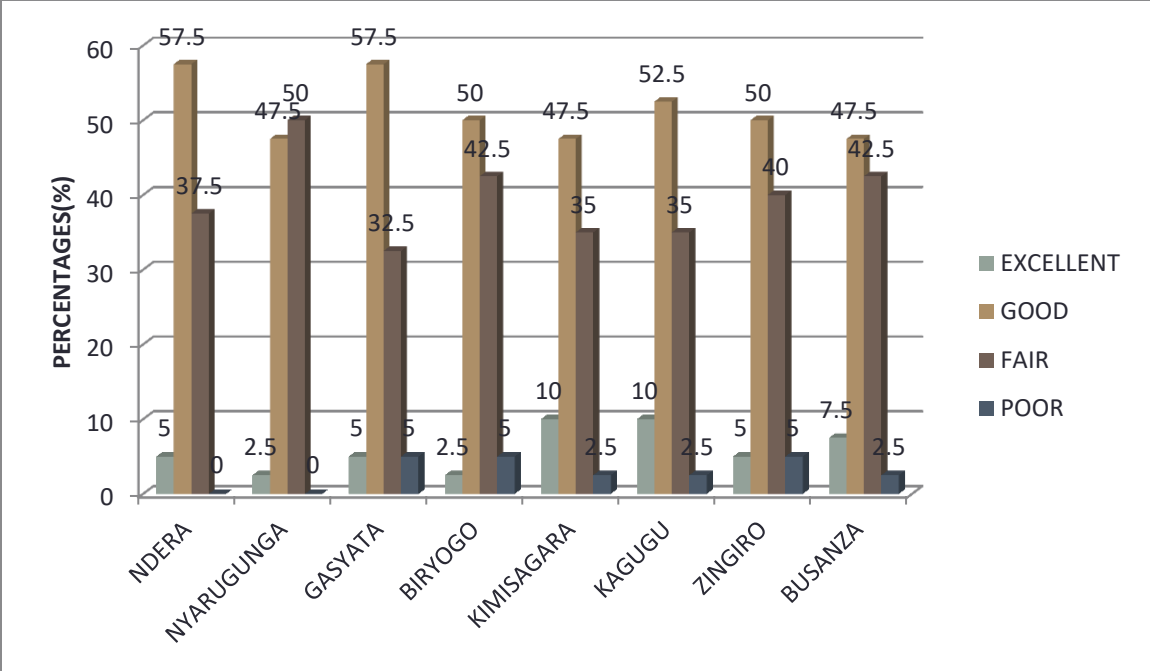


Figure 4.8: Consumer Perceptions on the color of Water

4.2.5. Customer Feedback on the Water Bill

Out of 320 valid respondents for the question of “What are your thoughts on the water bill?” The survey assessed respondents' perceptions of water costs using a four-point scale (Low, Average, High, and Very High). The study analyzed consumer feedback to assess the fairness of water tariffs, which are crucial for ensuring the service's financial sustainability. Figure 4.9 (from Table 4.G, Appendix) illustrates customer perceptions about the grading of Water bills. The survey results revealed that 48.75% of respondents rated it as average, 28.44% as high, 11.56% as very high, and 11.25% as low. Those who reported high rates tend to reside in multi-occupancy homes.

The current lifeline tariff generally does not benefit the poor. High-income customers living in single-family homes pay the lowest rate per meter cubed (m3) of water and receive the biggest subsidy, despite utilizing the most per person.

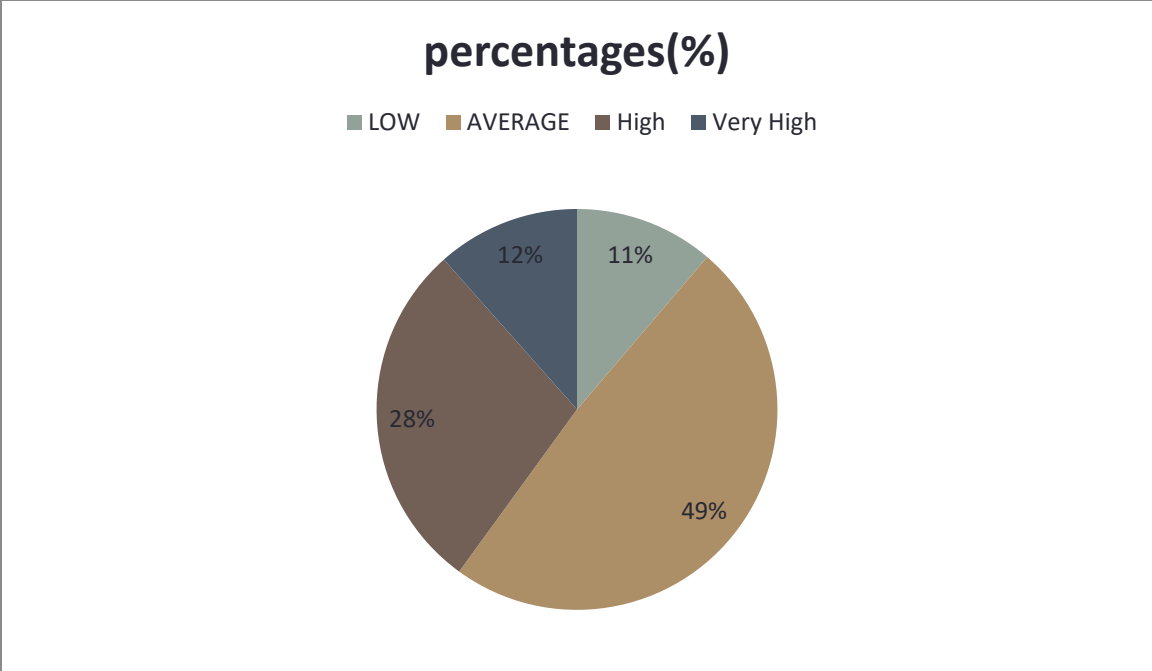


Figure 4.9: Consumer Perceptions on Water Bill

4.2.6. Measures to improve customer satisfaction

Several measures can be taken to improve consumer satisfaction with Kigali City's water supply services.

1. Increase service reliability and consistency.

Reduce Interruptions: Use modern monitoring and management systems to promptly identify and resolve problems that cause water supply interruptions.

Preventive Maintenance: Routine maintenance of the water supply infrastructure to avoid unexpected outages.

Alternate Water Sources: Develop and deploy alternate water sources to provide constant supply, especially during peak demand periods or in the event of emergency.

2. Improve water quality.

Regular Water Testing: Conduct regular water quality testing to ensure that the water fulfills national and international requirements. Publish the results to maintain transparency.

Water Treatment Upgrades: Invest in updating water treatment facilities to improve water quality for users.

3. Enhance customer communication and engagement.

Timely Notifications: Set up a method to notify consumers about scheduled maintenance, potential disruptions, or changes in water supply services.

Customer Feedback Mechanism: Create avenues (hotlines, online platforms, surveys) for customers to report problems and leave feedback on services. Regularly review and act on this feedback.

Neighborhood Engagement: Hold neighborhood meetings and awareness initiatives to educate customers about water conservation, usage, and attempts to enhance services.

4. Effective billing and customer support services.

Transparent Billing: Ensure billing clarity by providing full explanations of charges. Implement simple payment methods and flexible payment arrangements for customers experiencing financial challenges.

Responsive Customer Support: Build customer support teams to handle queries, complaints, and concerns more effectively and compassionately.

5. Improve Infrastructure: Expand the water distribution network to reach underserved communities for equal access to water services in Kigali.

Infrastructure Modernization: Improve aged infrastructure to reduce losses caused by leaks and inefficiencies in the system.

6. Put Intelligent Water Management Systems into Practice

Install smart water meters to give consumers real-time monitoring of their water usage and to assist them in more efficient consumption management.

Making Decisions Based on Data: To forecast and control water demand, optimize distribution, and pinpoint locations in need of improvement, apply data analytics.

7. Programs for affordability and subsidies

Subsidized Rates: To guarantee that everyone can afford basic water services, offer subsidized rates or support programs for low-income households.

Tariff Modifications: Water tariffs should be reviewed and adjusted on a regular basis to reflect the true cost of providing the service while keeping costs reasonable for customers.

4.3. Impact of Water shortage Analysis.

4.3.1. Effects of inadequate water supply.

Respondents were requested to provide feedback on issues caused by poor water supply and delivery in the Kigali Water network. Table 4.5 presents some assessments of their replies.

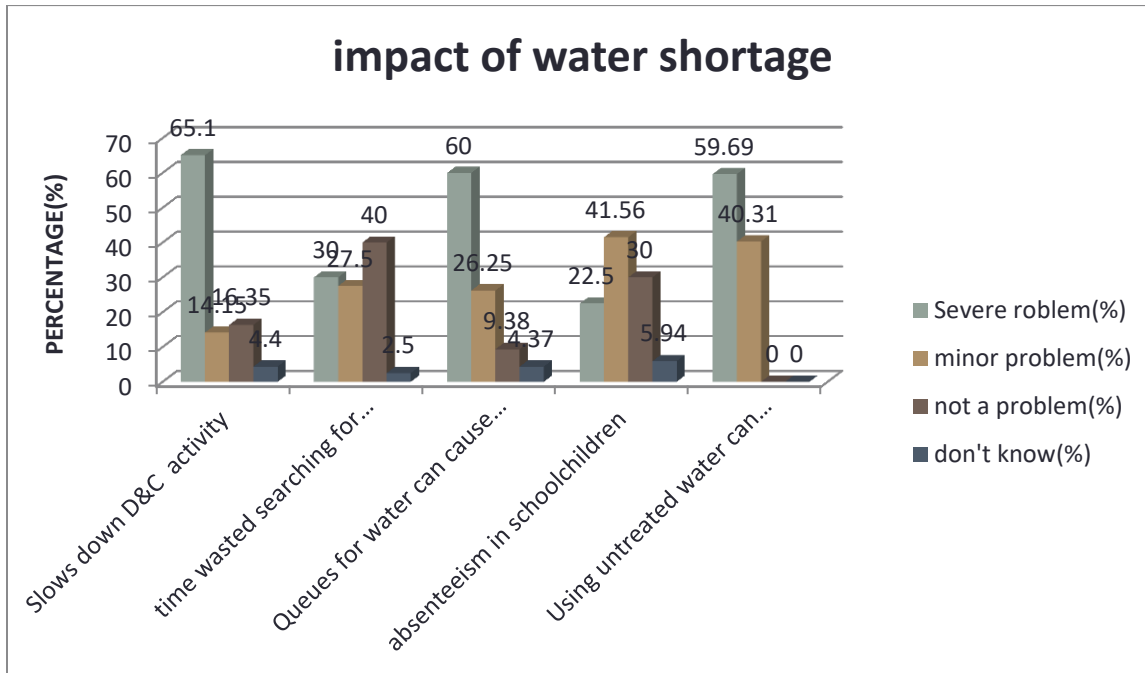


Figure 4.10. Effects of inadequate water supply in Kigali

Water shortages slow down domestic and commercial activities.

Figure 4.10 shows that out of 318 respondents, 252 (79.25%) said water shortages were a problem, 52(16.35%) said it was not a problem, and 14 (4.4%) were indifferent. Therefore Water shortages were identified as a major issue that reduce the speed of domestic and commercial development activities mainly in dry season.

Too much time waste for searching water

Access to water should be simple, yet wasting time searching for it might be problematic. According to Figure 4.10, 96 out of 320 respondents rated it as a severe problem (30%), 88 as a minor problem (27.5%), 128(40) as not a problem and 8 (2.5)said don't know . If the problem is expected to last longer than a few days, alternative water supply arrangements should be made available.

Queues for water can cause conflict.

To maintain order, individuals would typically join a queue and wait their turn for service. However, when others try to skip the queue due to delays, frustration and impatience can lead to arguments. According to Figure 4.10, 60% of respondents identified it as a severe problem, 26.25% as a minor problem 9.38% as not a problem and 4.37% indifferent. To address these issues, WASAC should collaborate with the private sector to create more sources like borehole points.

Using untreated water from streams and wells can pose risks.

Inadequate water and sanitation can lead to disease outbreaks via contaminated food, water, and hands, resulting to premature death and serious illness worldwide (UN, 1977). The Table shows that all respondents agreed on the necessity to address the issue of access to clean and safe water for all.

Risk lives of children and reason for tardiness

Everyone is aware of the times when water flows and is required to store water for later usage. When water service is abruptly disconnected, schoolchildren are the most affected as they must roam about to find water for their households. According to Figure 4.10 shows respondents acknowledge that this problem endangers children's lives and causes tardiness and absenteeism in school and rated respectively 32.5% and 22.5% as a severe problem 48.75% and 41.56% as a minor problem 11.56% and 30 as not a problem and 7.19% 5.79% said don't know.

4.3.2. Measures to reduce effects of water shortage.

A variety of short- and long-term solution can be put in place to lessen the effects of water shortage on Kigali City's water supply services functioning. These measures concentrate on enhancing the resilience of water supply overall while reduce the impacts of shortage on locals and businesses.

1. Create and carry out a backup plan for water shortages.

Plans for Emergency Water Supply: Provide explicit guidelines on how to handle water shortages, giving priority to vital services like hospitals, schools, and emergency response teams.

Other Sources of Water: Determine and create backup water sources that can be readily accessed in an emergency, such as emergency water tanks, rainfall collection systems, or groundwater wells.

2. Encourage water conservation when there are shortages

Limitations on Water Use: When there are severe water shortages, impose temporary water use restrictions, such as banning non-essential applications, lowering industrial water consumption, and restricting outdoor water use.

Campaigns for Public Awareness: Launch focused public awareness programs that include advice on how to cut back on water use at home and in companies, as well as the significance of conserving water during times of scarcity.

Rewards for Lower Consumption: Offer monetary rewards, such rebates or discounts, to individuals and companies who drastically cut back on their water use when there is a scarcity.

3. Upgrade Facilities to Cut Down on Water Losses

Leak Detection and Repair: In order to minimize losses and guarantee that consumers receive access to water, it is important to step up efforts to find and fix leaks in the water distribution system.

Programs for Pipe Replacement: Spend money replacing old, leaky, and inefficient pipelines, especially in locations where water shortages are most severe.

Water Pressure Management: Use pressure management strategies to cut down on water loss, particularly in high-leakage regions.

4. Increase Capacity for Storing Water

Construction of Reservoirs: To enhance the ability to store water during plenty and utilize it during shortages, build new reservoirs or enlarge existing ones.

Rainwater Harvesting: Promote the broad use of these systems in residential and commercial structures to supplement water supplies during dry spells.

5. Provide Aid to Communities in Need

Programs for Targeted Assistance: In times of scarcity, assist vulnerable groups, such as low-income homes, by providing free water delivery, subsidies, or access to communal water sources.

Water distribution using mobile tankers: Make sure that populations without access to piped water are not left without resources by deploying water tankers to deliver water in the most impacted areas.

6. Diversify water sources.

Groundwater Development: Invest in digging and maintaining wells to access groundwater supplies, which will provide an additional buffer during surface water shortages.

Water Reuse and Recycling: Encourage the reuse of treated wastewater for non-potable uses such as irrigation, industrial processes, and toilet flushing, hence lowering overall freshwater demand.

7. Engage the community in water management.

Community-based Water Management: Involve local populations in water management choices, particularly during shortages, to ensure that actions are tailored to local needs and circumstances.

Local Water Committees: Form local water committees to oversee the equitable distribution of water and handle any issues that may emerge during shortages.

By putting these strategies into practice, Kigali City can guarantee a more robust and dependable water delivery system while also considerably reducing the detrimental effects of water shortages on locals and companies

4.4. Water Quality analysis and Findings

4.4.1. Water quality analysis

Several characteristics were considered while establishing the water quality of the Kigali Water Network (public water sources). This section discusses the examined parameters and their significance. These parameters include a physical (pH, Temperature, Turbidity, Conductivity) chemical (chloride, total hardness, Total Dissolved Solid, Suspended Solid, Nitrate, phosphate, manganese, sulphate ,iron), and microbiological constituent that were analyzed on the water samples for the research.



Figure 4.11: laboratory testing water quality.

4.4.2. Findings and Discussion

The Figure 4.12 shows the findings of water samples collected from chosen households and compared to international (WHO) and national (Rwanda) standards. Water quality results for water samples are taken throughout the rainy season.

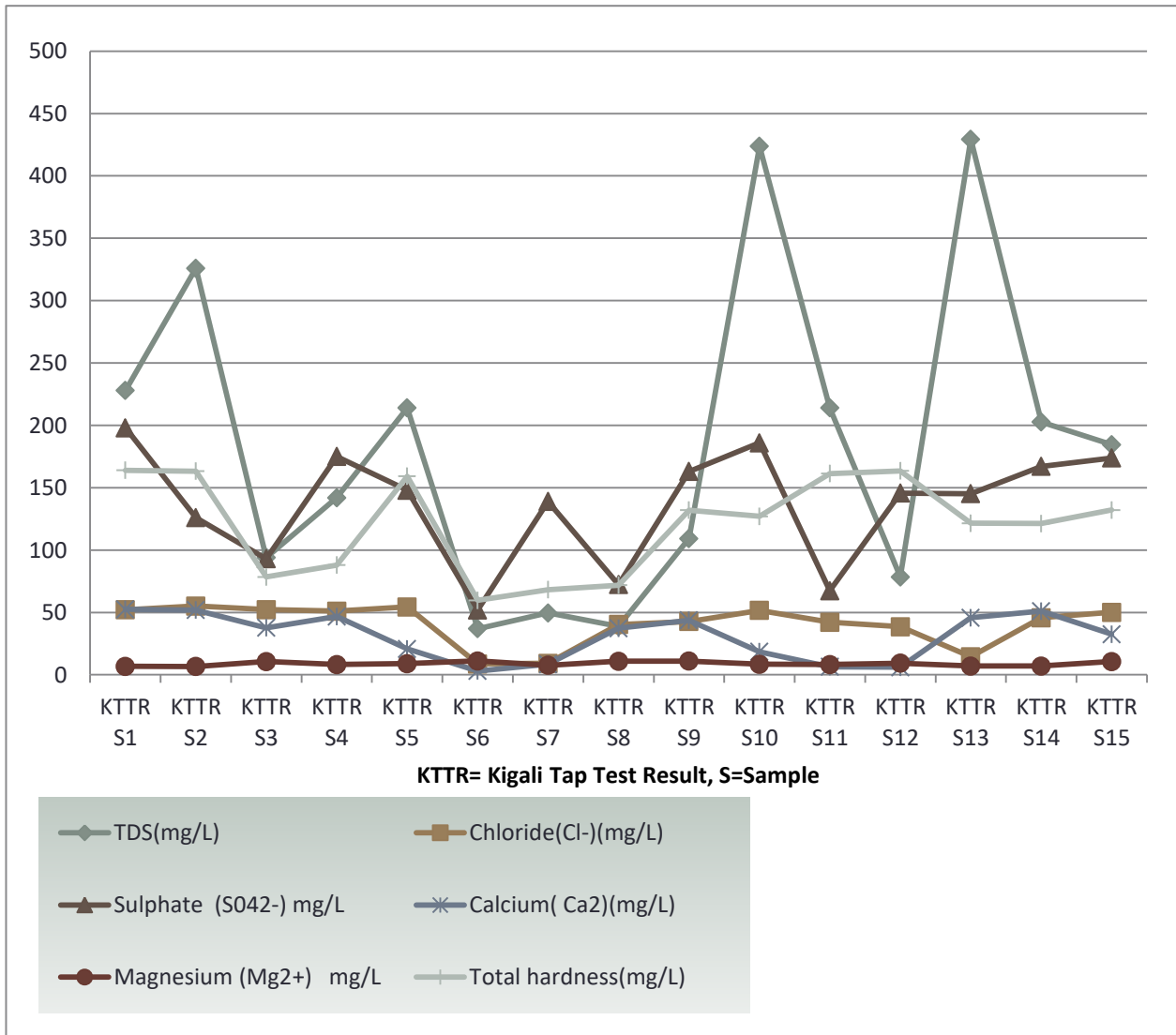


Figure 4.12. Laboratory result of water quality parameters

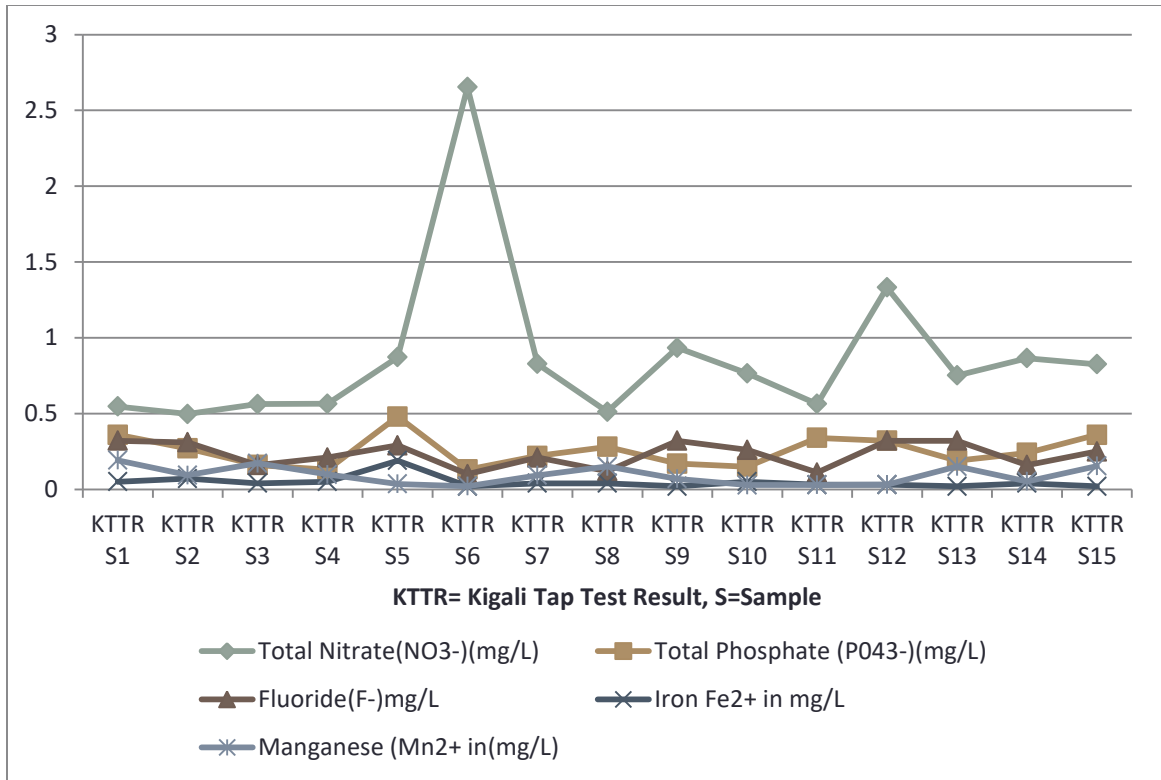


Figure 4.13. Laboratory result of water quality parameters continued

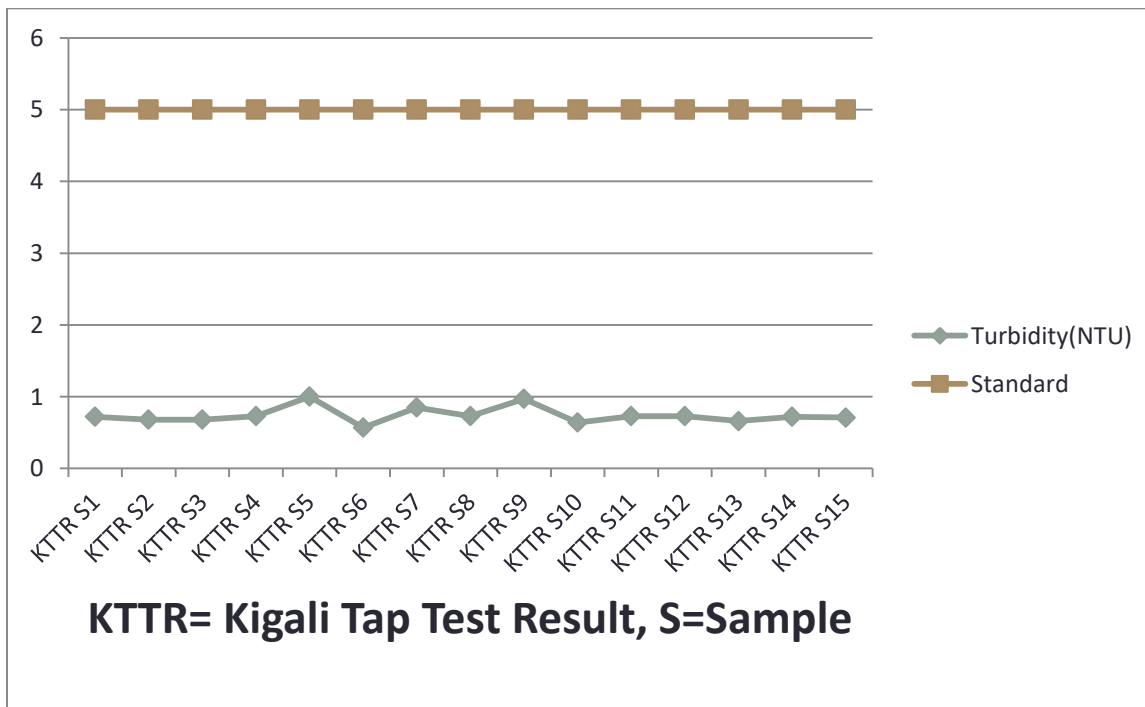


Figure 4.14. Laboratory result of Turbidity of water quality

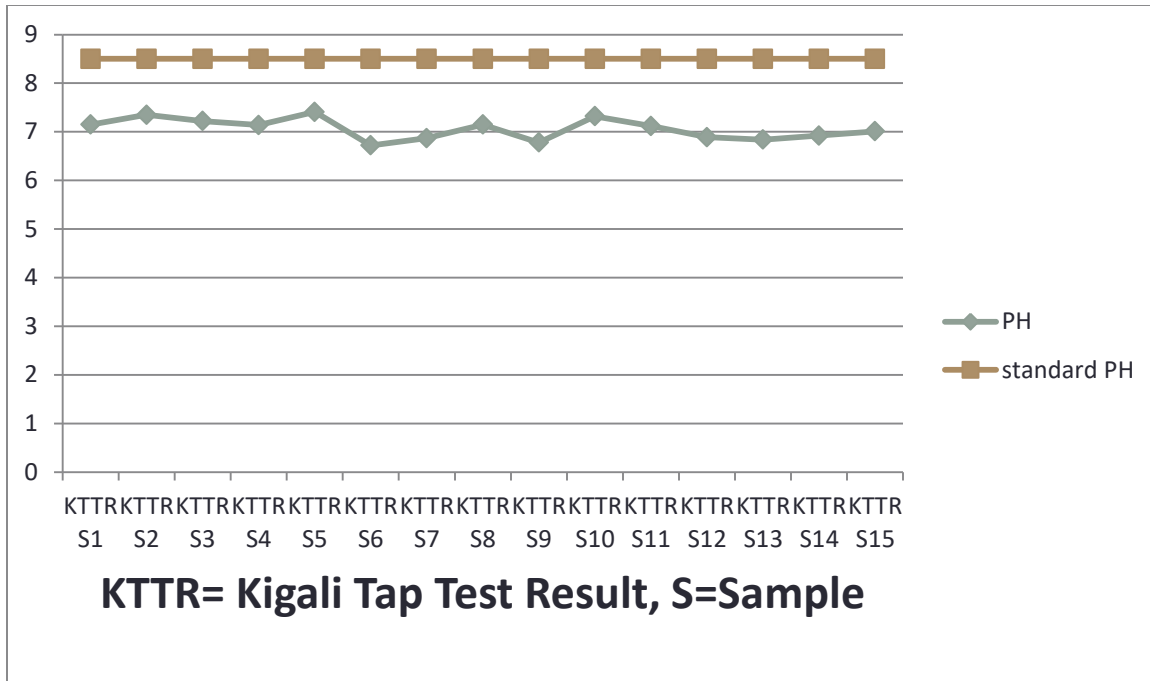


Figure 4.15. Laboratory result of PH of water quality

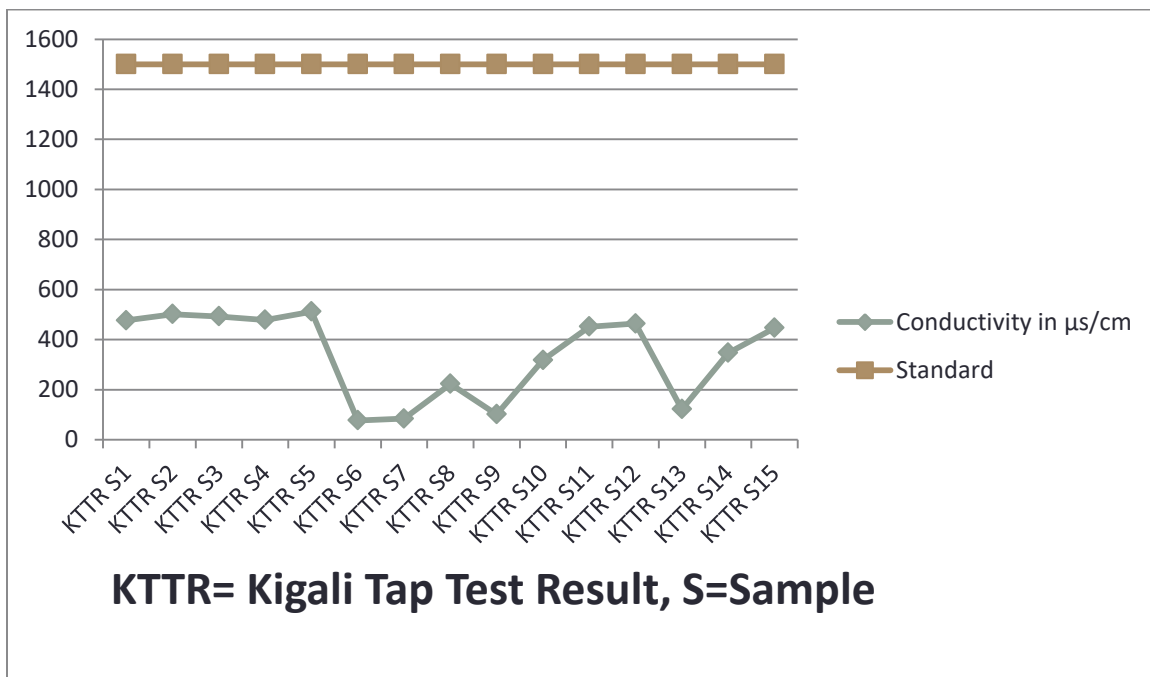


Figure 4.16. Laboratory result of conductivity of water quality

SUMMARY OF WATER QUALITY FINDINGS

The PH value of all taken water samples is within the range Of the national and international standard. The TDS value for all samples is within the national and international standards. However, this does not mean that the water Supply system is working well on the quality of pipe water supply because the observed TDS value in samples Kigali taps S2, S10, 13 are high. The overall hardness of all samples is within the appropriate range. The Nitrate, Sulphate and phosphate values for all samples are within the national and international standards. The calcium and Magnesium value of all taken water samples is within the range Of the national and international standard. The iron value of all taken water samples is within the range Of the national and international standard. Therefore the manganese value for Kigali tap S1, 3,8,13 and 15 samples are deviated from national and international standards means that Organic-rich pollution sources (e.g. runoff from landfills, compost, brush or silage piles, or chemicals such as gasoline) might contribute to the background level by enhancing manganese release from soil to water supply system. The turbidity of the samples taken from all sources is in acceptable range both national and international standard. The total coliform for all samples deviates significantly from both national and internal standards. This demonstrates that drinking water supply system can be contaminated by storm water runoff during the leakage of pipes, discharges from sewage treatment or septic systems. The presence of coliform bacteria in water does not The guarantee that drinking it will cause an illness, rather, it indicates that a contamination pathway exists between a source of bacteria (surface water, septic system, animal waste, etc.)And water supply; disease –causing bacteria may use this path way to enter the water supply because coliform bacteria typically stay in water longer than most disease-causing organism, the absence of coliform bacteria leads to the presumption that the water supply is microbiologically safe to drink. As shown in table above ,the overall hardness of water samples collected from various residences taps fall below national and international criteria, and the water in the present water delivery system is soft. This can lead to pipe corrosion, which can limit the life span of the pipes in the water supply system, and the corrosion can result in the pollution of drinking water, which can have negative impact on its taste and appearance. For Cl^- water concentration above 250mg/L, the taste becomes salty and becomes increasingly objectionable. All samples have less chloride content than national and international standards, as shown in table .this suggests that the system's chlorination is low, resulting in high coliform levels in water.

4.4.3. Measures to guarantee excellent water quality.

A number of crucial actions need to be taken in order to guarantee excellent water quality and enhance Kigali City's water supply services. The fundamental goal of these initiatives is to keep clean, safe water flowing from the source to the faucet, guaranteeing that all homes and businesses have access to water that complies with health and safety regulations.

1. Implement rigorous water quality monitoring.

Increase the frequency of water quality monitoring at various locations throughout the distribution system, such as the source, treatment plants, and customer taps, to detect any potential pollution.

Real-time Monitoring Systems: Implement real-time water quality monitoring systems that continuously measure critical parameters (such as turbidity, pH, and chlorine levels) and notify authorities of any anomalies.

Compliance with Standards: Ensure that the delivered water consistently fulfills national and international water quality requirements, particularly those established by the World Health Organization (WHO).

2. Strengthen the Integrity of the Distribution System

Leak Prevention: To keep contaminants out of the system and cut down on water loss, periodically check for and fix leaks in the distribution network.

Pipe Replacement: In places with aging infrastructure, specifically, replace old, corroded pipes that could leak dangerous materials into the water.

Backflow Prevention: To stop non-potable sources from contaminating the potable water supply, install backflow prevention devices at key distribution system locations.

3. Encourage the safe handling and storage of water

Campaigns for Public Education: Inform locals of the value of using clean containers and preventing contamination while storing and handling water.

Secure Water Storage Options: To stop contamination in households and companies, provide or subsidize safe water storage containers, like those with tight apertures and caps.

Home Water Treatment: Promote the use of home water treatment techniques, such as filtration, boiling, or chlorination, particularly in locations where the quality of the water may be in danger.

4 Consolidate Regulatory Monitoring

Frequent Audits: To make sure that water quality requirements and regulations are being followed, conduct routine audits of water treatment and distribution facilities.

Regulation Enforcement: Enforce severe penalties for water utilities, businesses, and other organizations that might be involved in contaminating breaking water quality regulations.

Accountability and Transparency: Make water utilities publish reports on water quality on a regular basis. This will ensure accountability by providing the public with access to the information.

5. Engage and educate the community.

Community Water Quality Monitoring: Engage communities in monitoring water quality by training them to recognize indicators of contamination and reporting problems to authorities.

Public Awareness Campaigns: Run continuing public awareness efforts to educate locals about water quality issues, the value of safe drinking water, and how they may help maintain the supply.

By implementing these strategies, Kigali City can greatly enhance the quality of its water supply, ensuring that all inhabitants have access to safe, clean, and reliable water, as well as improving overall water supply service performance.

Chapter 5. Conclusion and Recommendation

5.1. Conclusion

The performance review of Kigali's water supply service provides extensive insights into the system's reliability, customer satisfaction, the impact of water shortages, and water quality compliance.

Reliability of water supply: The review finds that, while there have been improvements in water supply infrastructure and management, issues persist in guaranteeing a consistent and reliable supply to satisfy the daily demands of households and businesses. Intermittent supply disruptions and fluctuating pressure levels are challenges that must be addressed in order to improve overall reliability.

Customer satisfaction: Customer satisfaction percentages indicate moderate approval of water supply services. Many locals recognize the progress made in recent years; yet, complaints about frequent shortages, inconsistent supply schedules, and sometimes bad service responses emphasize areas that require additional development. Improved contact with customers and prompt resolution of concerns could dramatically boost satisfaction rates.

Impact of water shortage: The evaluation demonstrates that water shortages have a major negative impact on Kigali citizens. These shortages have an impact on daily life, particularly in low-income neighborhoods, as well as disrupting business operations, resulting in economic losses. To minimize these negative effects, a more equal and reliable water distribution system must be established.

Water quality compliance: The quality of water that consumers get generally meets set water quality standards. Regular monitoring and rigorous quality control techniques have guaranteed that the water is safe to drink. However, there is potential for improvement in ensuring uniform quality across all distribution locations, especially during peak demand or infrastructure repair.

In conclusion Kigali's water supply service has made significant progress in recent years; nonetheless, ongoing efforts are required to improve its reliability, boost customer satisfaction, alleviate the effects of water shortages, and assure consistent water quality. Addressing these difficulties will be important in fulfilling the increased demand and ensuring a sustainable water future for Kigali's people and companies.

5.2. Recommendation

1. Improve the reliability of water supply:

- Explore and develop alternate water sources, such as rainfall gathering and groundwater extraction, to supplement existing supplies and provide more constant distribution.
- Implement demand management measures, such as water-saving devices and public awareness campaigns, to optimize water consumption and reduce waste
- Invest in updating the current water delivery infrastructure to improve capacity and eliminate leaks. Modernizing pipes, water meters, and storage facilities can help to reduce disruptions.

2. Enhance customer satisfaction:

- Create effective customer feedback mechanisms to gain insights into service faults and areas for development. Regular surveys and interactive platforms can assist residents identify their concerns and make suggestions.
- Maintain open communication about water supply schedules, repair activities, and potential delays. Keeping residents informed might assist to manage expectations and reduce frustration.

3. Mitigate Impact of water shortage:

- Ensure more equal water distribution among neighborhoods, with a focus on places that are more vulnerable to shortages. This can be accomplished with better network management and strategic planning.
- Provide assistance to individuals and companies affected by water scarcity, such as subsidies for water-saving equipment and incentives for business that implement water-efficient practices.

4. Ensure compliance of water quality:

- Increase the frequency and scope of water quality monitoring and testing to guarantee consistent adherence to set criteria. Use modern technologies to assess water quality in real time.
- Invest in training and capacity building for water supply professionals to ensure they have the knowledge and skills needed to continuously maintain high water quality standards.

Implementing these proposals will necessitate collaborative efforts by the Kigali Water Supply Authority, local governments, and community groups. By addressing the primary issues identified in the performance evaluation, Kigali may attain a more dependable, satisfying, and long-term water delivery service that fulfills the needs of its rising population and vibrant economy.

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Appendix 1:
RESIDENTS'QUESTIONNAIRE.

As part of the requirement for the award of Maters at University of Rwanda college of science and technology in the Department of Civil, Environmental and Geomatic Engineering faculty of Water Resources and Environmental Management. I, Theoneste HAKIZIMANA with registration number 220020088 conducting a research dissertation study on the topic “Performance Evaluation of Water Supply Service in Kigali City”.

Your honest response will be greatly appreciated, and I would be very grateful if you could support this study by answering this questionnaire. I can be sure that your response will be kept private and anonymous. Please mark (√) the relevant boxes and provide a response where necessary.

Section 1: Socio-Demographic characteristics of respondents

1. Sex:

(a) Male ()

(b) Female ()

2. Age (years)

(a) 18-30 ()

(b) 31-40 ()

(c) 41-50 ()

(d) 51 and above ()

3. What is your highest level of education?

Primary ()

Secondary/Tech. ()

University/Tertiary ()

None ()

Section B: Flow Condition

1. How many are you in your household?
(a) 1-3 () (b) 4-7 () (c) 8-10 () (d) above 10 ()
2. How many days a week do you get water?
(a) 1-2days (b) 3-4 days (c) 5-6 days (d) weekly ()
3. How many hours a day do you get water?
(a) Less than 8 hours () (b) Between 8-16 hours () (c) 16-24 hours ()?
4. How much liters of water does your home require daily on average?
(a) 20-40 () (b) 40-80() (c)80-120() (d) 120-160 e) 160 and above
5. Is the water you fetch enough to suit your household needs?
(a) Yes (b) NO
6. Do you have another supply of water? (a) Yes. (b) No.
If yes, what's the source?
(a) Well or borehole () (b) Rainwater () (c) Streams/Lakes () (d) Private Providers ()

Section C: Water quality

1. What are your thoughts on the physical and taste quality of the water?
(a) Excellent () (b) Good () (c) Fair () (d) Poor ()
2. What are your thoughts on the physical water quality - smell?
(a)Excellent () (b) Good () (c) Fair () (d) Poor ()
3. What is your opinion of the physical water quality - colour?
(a)Excellent () (b) Good () (c) Fair () (d) Poor ()

Section D: Billing

1. Is your water supply metered? (a)Yes (b) No
2. Is your meter read regularly? (a)Yes (b) No
3. Do you regularly receive bills? (a)Yes (b) No
4. What is the average amount you pay each month for water? frw
(a) 600 - 1000 (b) 1000 - 3000 (c) 3000 - 5000 (d) Above 5000
5. What are your thoughts on the water bill?
(a) Low (b) Average (c) High (d) Extremely high
6. Do you think water bills should be increased in order to improve water supply and Delivery services? (a) Yes (b)No

Section F: issues about Inadequate Water Supply

1. What are your thoughts on the following problems with the city of Kigali's water supply and delivery system? Mark (√) the relevant columns below :(a) Severe problem; (b) Minor problem; (c) Not a problem and (d) Don't know in the table below.

Issues	Severe Problem	Minor problem	Not a Problem	Don't know
Slows down domestic and commercial activity				
Too much time wasted searching for water.				
Queues for water can cause conflict.				
Reasons for tardiness and absenteeism in schoolchildren.				
Children risk their lives searching for water.				
Using untreated water from streams and wells can pose risks.				

Appendix 2

Table 4.A: Gender and age distribution of respondents.

Age	Male	Percentage (%)	Female	Percentage (%)
Below 30	42	25	67	44.1
30-45	95	56.55	46	30.26
Above 45	31	18.45	39	25.65
Total	168	100	152	100

Table 4.B. Respondents Education level

Educational level	Frequency	Percentage (%)
University	80	25
secondary	173	54.0625
primary	62	19.375
none	5	1.5625
Total	320	100

Table 4.C: Hours of flow in a day.

Hours in a day	0—8 hours	%	8—16 hours	%	16-24 hours	%
NDERA	9	22.5	18	45	13	32.5
NYARUGUNGA	11	27.5	12	30	17	42.5
GASYATA	12	30	15	37.5	13	32.5
BIRYOGO	8	20	14	35	18	45
KIMISAGARA	12	30	19	47.5	9	22.5
KAGUGU	15	37.5	11	27.5	14	35
ZINDIRO	13	32.5	14	35	13	32.5
BUSANZA	17	42.5	13	32.5	10	25
Total	97	30.31	116	36.25	107	33.44

Table 4.D: Consumer Perceptions on the Taste of Water

Assessment	Excellent	%	Good	%	Fair	%	Poor	%
NDERA	6	16.67	17	47.22	12	33.33	1	2.78
NYARUGUNGA	4	10.53	20	52.63	13	34.21	1	2.63
GASYATA	7	19.44	18	50	10	27.78	1	2.78
BIRYOGO	10	25.64	13	33.33	13	33.33	3	7.69
KIMISAGARA	3	10.35	14	48.26	11	37.93	1	3.45
KAGUGU	5	14.71	18	52.94	9	26.47	2	5.88
ZINDIRO	4	11.11	14	38.88	17	47.22	1	2.77
BUSANZA	3	8.33	12	33.33	15	41.66	2	5.55
Total	42	15	126	45	100	35.71	12	4.29

Table 4.E: Consumer Perception of the Smell of Water.

Assessment	Excellent	%	Good	%	Fair	%	Poor	%
NDERA	8	20	20	50	11	27.5	1	2.5
NYARUGUNGA	4	10	16	40	20	50	0	0
GASYATA	9	22.5	16	40	13	32.5	2	5
BIRYOGO	6	15	18	45	15	32.5	1	2.5
KIMISAGARA	2	5	23	57.5	12	30	3	7.5
KAGUGU	7	17.5	21	52.5	10	25	2	5
ZINDIRO	6	15	17	42.5	14	35	3	7.5
BUSANZA	5	12.5	22	55	11	27.5	2	5
Total	47	14.688	153	47.8125	106	33.125	14	4.375

Table 4.F: Consumers' Perception of Water Color.

Assessment	Excellent	%	Good	%	Fair	%	Poor	%
NDERA	2	5	23	57.5	15	37.5	0	0
NYARUGUNGA	1	2.5	19	47.5	20	50	0	0
GASYATA	2	5	23	57.5	13	32.5	2	5
BIRYOGO	1	2.5	20	50	17	42.5	2	5
KIMISAGARA	4	10	19	47.5	14	35	3	2.5
KAGUGU	4	10	21	52.5	14	35	1	2.5
ZINDIRO	2	5	20	50	16	40	2	5
BUSANZA	3	7.5	19	47.5	17	42.5	1	2.5
Total	19	5.9375	164	51.25	126	39.375	11	3.4375

Table 4.G: Consumers' perception of billing

Assessment	Low	Average	High	Very high
NDERA	4	18	13	5
NYARUGUNGA	6	21	9	4
GASYATA	2	18	12	8
BIRYOGO	5	21	13	1
KIMISAGARA	4	19	12	5
KAGUGU	3	20	10	7
ZINDIRO	7	22	8	3
BUSANZA	5	17	14	4
Total	36	156	91	37
Percentage (%)	11.25	48.75	28.44	11.56

Appendix 3:

Table 4.2: Water demand for year 2022

Category	Water requirement	Water demand for year 2022
Domestic	120 l/c/d	209,466,600 l/d
Public utilities	30 l/p/d	52,366,650 l/d
Commercial Centre	15 l/p/d	26,183,325 l/d
Fire	35 l/p/d	61,094,425 l/d
Institutional	15l/p/d	52,336,650 l/d
Total Demand		375,300,325 l/d

Table 4.3. : Water demand for year 2023

Category	Water requirement	Water demand for year 2023
Domestic	120 l/c/d	218,015,040 l/d
Public utilities	30 l/p/d	54,505,760 l/d
Commercial Centre	15 l/p/d	27,251,880 l/d
Fire	35 l/p/d	63,587,720 l/d
Institutional	15l/p/d	27,251,880 l/d
Total Demand		390,612,280 l/d

Table 4.4: water demand for year 2024

Category	Water requirement	Water demand for year 2024
Domestic	120 l/c/d	226,912,440 l/d
Public utilities	30 l/p/d	56,728,110 l/d
Commercial Centre	15 l/p/d	28,364,055 l/d
Fire	35 l/p/d	66,182,795 l/d
Institutional	15l/p/d	28,364,055 l/d
Total Demand		406,551,455 l/d

Table 4.5.: issues about inadequate water supply

Issues	Severe Problem	%	Minor problem	%	Not a Problem	%	Don't know	%
Slows down domestic and commercial activity	207	65.1	45	14.15	52	16.35	14	4.40
Too much time wasted searching for water.	96	30	88	27.5	128	40	8	2.5
Queues for water can cause conflict.	192	60	84	26.25	30	9.38	14	4.37
Reasons for tardiness and absenteeism in schoolchildren.	72	22.5	133	41.56	96	30	19	5.94
Children risk their lives searching for water.	104	32.5	156	48.75	37	11.56	23	7.19
Using untreated water from streams and wells can pose risks.	191	59.69	129	40.31	0	0	0	0

Table 4.6. Laboratory result of water quality analysis

S.No	Parameter	Unit	Kigali tap S1 Test result	Kigali tap S2 Test result	Kigali tap S3 Test result	Kigali tap S4 Test result	Kigali tap S5 Test result
1	PH		7.15	7.35	7.22	7.14	7.41
2	TDS	Mg/L	228	326	94	142	214
3	Turbidity	NTU	0.72	0.68	0.68	0.73	1.002
4	Conductivity	µs/cm	477	502	493	479	512
5	Chloride(Cl ⁻)	mg/L	52.052	55.123	52.235	51.032	54.402
6	Total Nitrate(NO ₃ ⁻)	mg/L	0.546	0.497	0.562	0.564	0.871
7	Total Phosphate (PO ₄ ³⁻)	mg/L	0.36	0.27	0.16	0.13	0.48
8	Sulphate (SO ₄ ²⁻)	mg/L	198	126	93	175	148
9	Fluoride(F ⁻)	mg/L	0.32	0.31	0.16	0.21	0.29
10	Iron(Fe ²⁺)	mg/L	0.05	0.07	0.04	0.05	0.19
11	Manganese (Mn ²⁺)	mg/L	0.192	0.094	0.172	0.098	0.036
12	Calcium(Ca ²⁺)	mg/L	52.448	51.901	37.629	46.754	20.683
13	Magnesium (Mg ²⁺)	mg/L	6.778	6.707	10.582	8.221	8.947
14	Total hardness	mg/L	163.96	163.21	78.43	87.95	159.12
15	Total coliform	MPN/ 100mL	0.01673	0.00032	0.02140	0.01165	0.00082

S.No	Parameter	Unit	Kigali tap S6 Test result	Kigali tap S7 Test result	Kigali tap S8 Test result	Kigali tap S9 Test result	Kigali tap S10 Test result
1	PH		6.72	6.87	7.15	6.78	7.32
2	TDS	mg/L	36.9	49.62	38.72	109.23	423.7
3	Turbidity	NTU	0.57	0.85	0.73	0.097	0.64
4	Conductivity	µs/cm	77.2	84.18	223	101.7	318.2
5	Chloride(Cl ⁻)	mg/L	8.663	9.173	40.38	42.7	51.61
6	Total Nitrate(NO ₃ ⁻)	mg/L	2.653	0.827	0.512	0.934	0.765
7	Total Phosphate (PO ₄ ³⁻)	mg/L	0.13	0.22	0.28	0.17	0.15
8	Sulphate (SO ₄ ²⁻)	mg/L	52	139	72.3	163	186
9	Fluoride(F ⁻)	mg/L	0.10	0.21	0.12	0.32	0.26
10	Iron(Fe ²⁺)	mg/L	0.02	0.04	0.04	0.02	0.05
11	Manganese (Mn ²⁺)	mg/L	0.021	0.092	0.151	0.069	0.028
12	Calcium(Ca ²⁺)	mg/L	3.056	8.4	37.35	43.69	18.41
13	Magnesium (Mg ²⁺)	mg/L	11.116	7.67	10.84	11.002	8.402
14	Total hardness	mg/L	59.68	68.24	71.82	132	127.1
15	Total coliform	MPN/100mL	0.01872	0.01467	0.0084	0.06701	0.01034
S.No	Parameter	Unit	Kigali tap S11 Test result	Kigali tap S12 Test result	Kigali tap S13 Test result	Kigali tap S14 Test result	Kigali tap S15 Test result
1	PH		7.12	6.89	6.84	6.92	7.01
2	TDS	mg/L	214	78.4	429.36	202.7	184.5
3	Turbidity	NTU	0.73	0.73	0.66	0.72	0.71
4	Conductivity	µs/cm	452	464	122	347	447
5	Chloride(Cl ⁻)	mg/L	42.1	38.5	14.5	45.73	50.03
6	Total Nitrate(NO ₃ ⁻)	mg/L	0.563	1.332	0.751	0.865	0.825

7	Total Phosphate PO_4^{3-}	mg/L	0.34	0.32	0.19	0.24	0.36
8	Sulphate (SO_4^{2-})	mg/L	67.4	145.7	145.2	167.1	173.82
9	Fluoride(F^-)	mg/L	0.11	0.32	0.32	0.16	0.25
10	Iron(Fe^{2+})	mg/L	0.03	0.03	0.02	0.04	0.02
11	Manganese (Mn^{2+})	mg/L	0.029	0.031	0.151	0.052	0.154
12	Calcium(Ca^{2+})	mg/L	6.4	6.1	45.7	51	32.51
13	Magnesium (Mg^{2+})	mg/L	8.19	9.341	7.045	7.047	10.6
14	Total hardness	mg/L	161.3	163.5	121.52	121.3	132.12
15	Total coliform	MPN/ 100mL	0.00564	0.00306	0.0141	0.02282	0.02014