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Assessment of Water Supply Reliability and Future Demand in Ishaka Subcounty, Uganda

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Abstract

This study assesses the current reliability and future demand of the water supply system in Ishaka Subcounty, Uganda a rural-urban transition zone facing significant water security challenges. Using a mixed-methods approach, primary data were collected from 384 households and key informants through structured questionnaires and interviews, supplemented by secondary data from the National Water and Sewerage Corporation (NWSC). Descriptive and time-series analyses were employed to evaluate supply reliability, demand patterns, and institutional performance. Results indicate that 75% of households rely on NWSC piped water as their primary source, with 48.2% rating it as “very reliable.” However, intermittent supply, seasonal variability, and dependence on alternative sources such as boreholes (7.3%) and rainwater (7.0%) highlight persistent gaps in coverage and consistency. Infrastructure was perceived as efficient by 49.9% of respondents, though nearly half reported monthly service interruptions. Technological adoption for water management was widespread (83.9%), and community satisfaction with local water governance was high (88.5%). Time-series forecasting using an ARIMA (0,1,0) model revealed a steady annual increase in water demand, closely correlated with population growth. Projections indicate a continued rise in consumption from approximately 252.95 million litters in 2024 to an estimated 270 million litters by 2034. Household water use averaged 160.7 litres per day from the questionnaire, with domestic purposes accounting for 85% of total consumption. The study concludes that while the existing water supply system in Ishaka Subcounty is relatively reliable and well-regarded, rising demand driven by population growth and urbanization will likely strain current infrastructure. Strategic investments in network expansion, leak reduction, integrated water resource management, and enhanced policy implementation are recommended to ensure sustainable and equitable water access in the future.

1 INTRODUCTION

A basic human need and an essential element of sustainable development is having access to a clean and consistent supply of water (Gendeshmin et al., 2025; Rana et al., 2024). While the infrastructure plays a significant role to distribute the water from the source to consumers (Kuczera & Diment, 1988). The main objective of any water supply system is providing the necessary water to meet the water demand of a region or population. (Tang, 2000)..

Water demand dynamics refer to the changes in water usage over time, which are influenced by various factors such as population growth, economic development, technological advancements, and environmental conditions(Capone & Marston, 2025). As the population and economic activities in a region increase, the water demand typically rises. This increased water demand puts pressure on the water supply system, requiring it to adapt and expand its capacity to meet the growing needs (Amit & Sasidharan, 2019; Sorenson et al., 2011). Therefore, a water supply system must be designed and managed to account for these dynamic changes in water demand (Bartram et al., 2014).

On the other hand, the characteristics of the water supply system, such as the availability of water resources, water treatment and distribution infrastructure, and water pricing, can also influence water demand dynamics (Rathnayaka et al., 2016; Walton et al., 2009). For example, if the water supply system is limited or the cost of water is high, it can lead to a reduction in water consumption and a shift in water usage patterns. The provision of a reliable and clean water supply is a critical component of urban infrastructure (Abellán, 2017; Baba, 2018).

Water supply system development and urbanization have historically been highly correlated (Mala-Jetmarova et al., 2015). The construction of brick-lined wells and the excavation of shallow wells were among the first innovations in antiquity. This was evident in the Indus River basin as early as 2500 BCE (Bartram et al., 2014). As urban areas grew, there was an increasing need to route water supplies from distant sources. This resulted in the development of remarkable aqueduct systems, such those that were erected throughout the Roman Empire between 312 BCE and 455 CE(Bailey et al., 2021).

Over time, advancements in materials and technology have enabled the development of more sophisticated water supply systems (Abellán, 2017). The introduction of cast iron pipes with high-pressure joints in the early 19th century, along with the application of steam-powered pumping, allowed for the direct delivery of drinking water to individual homes, a significant improvement over the previous reliance on public fountains and water carriers (Vuorinen et al., 2007).

To address the unique challenges faced by urban areas, various innovative solutions have been implemented. For example, the city of Hong Kong, which lacks adequate local water sources, has resorted to building extensive reservoirs in the sea, such as the Plover Cove and High Island Reservoirs, to augment its water supply (Yue & Tang, 2011). Additionally, Hong Kong has pioneered the use of seawater for toilet flushing, conserving precious freshwater resources for drinking and other essential uses (Chen, 2001).

In Uganda, the challenges surrounding water and sanitation are worsened by rapid urban growth and a rising population(Marks et al., 2020; Musoke et al., 2018). Over the past two decades, Uganda has experienced significant economic growth, prompting many people to migrate from rural areas to informal settlements in and near urban centres. The urban population has surged from 7.9 million in 2018 (representing 23.6% of the total population) to an estimated 10.4 million by 2023, growing at a rate of 5.7% annually(Hermelink et al., 2023). This rapid urbanization has put considerable strain on the nation's water supply infrastructure (Sakomoto et al., 2020; Whittington et al., 1998).

Climate change is further aggravating water supply issues in Uganda’s urban areas(Bwire et al., 2020; Mugumya et al., 2020). Changes in rainfall patterns such as alterations in timing, intensity, and variability can affect the consistency and availability of surface and groundwater resources that cities rely on(Sakomoto et al., 2020). Higher temperatures can also lead to increased rates of evapotranspiration, which further reduces water supply (Hermelink et al., 2023). Moreover, the growing frequency and severity of extreme weather events like droughts and floods pose significant risks to urban water infrastructure, causing damage to treatment plants, distribution systems, and storage facilities (Walekhwa et al., 2022).

In Ishaka Subcounty, a rural-urban transition zone within Bushenyi-Ishaka, water supply and sanitation services reflect a mix of urban and rural characteristics. Although piped water is generally safer, challenges persist in ensuring consistent supply and quality, especially in areas farther from the main

network. Some piped sources are intermittent or contaminated, and alternative sources like boreholes and wells often have unsafe bacterial contamination, posing health risks. These issues highlight the need for improved water treatment, regular monitoring, and expanded infrastructure to ensure reliable and safe water access for all (Marks et al., 2020)

In Ishaka subcounty, the primary water supply system is a combination of piped water infrastructure and alternative sources such as protected springs, boreholes, and gravity flow schemes. The piped water system is managed by the National Water and Sewerage Corporation (NWSC), a government-owned public utility responsible for providing water supply and sanitation services in urban areas across Uganda. NWSC has been operating in Bushenyi-Ishaka Subcounty for over a decade and sources water primarily from the Nyaruzinga and Kitagata wetlands. However, studies have noted that water from the Nyaruzinga wetland often has acidic pH levels, necessitating treatment before distribution to meet national water quality standards(Kanyesigye et al., 2024).

In peri-urban and less developed parts of the municipality, residents frequently rely on non-piped water sources, particularly where the NWSC network does not reach. These community-managed systems play a crucial role in bridging service gaps and are often supported by local government and NGOs. Overall, while NWSC provides the formal water supply backbone for the municipality, alternative sources remain vital for inclusive access, especially in underserved zones (Marks et al., 2020).

According to Marks et al. (2020), Most families in Bushenyi Ishaka municipality primarily depend on protected springs (48%), unprotected springs (20%), and piped water connections from the National Water and Sewerage Corporation (NWSC) (18%) for their drinking water, while the remaining 14% uses other sources. Households in the more urban, densely populated districts of the municipality are more likely to use improved water sources, such as piped water on-premises, while those in the rural, lower-density areas tend to rely more on unprotected spring (Daniel et al., 2020; Paul, 2018).

Access to water sources also varies across the rural-urban spectrum (Geleijnse et al., 2023). Households in the more urban areas have better access, with about one-fifth having their main water source located on their premises (Kanyesigye et al., 2023; Sanchez et al., 2020). However, many households, especially in the rural areas, still have to spend significant time fetching water, with a median one-way trip time of 20 minutes for sources like boreholes and streams (Sanusi et al., 2024).

Water availability also differs by season, with most sources experiencing reduced hours of service during the dry months compared to the rainy season (Nyakutsikwa, 2018). Many households (56%) supplement their main drinking water source with rainwater harvesting during the rainy periods (Paul, 2018; Sanchez et al., 2020). Kanyesigye et al., (2023) found that the majority of households (72%) use unlined pit latrines not designed for safe emptying and reuse, pointing to challenges in sanitation service provision across the subcounty. Accurate assessment of demand dynamics allows planners to anticipate future needs and avoid mismatches between supply capacity and user requirements, especially in rapidly urbanizing areas like Ishaka Subcounty (Sadoff et al., 2015).

Access to safe and reliable drinking water remains a major challenge in Bushenyi District, where Ishaka Subcounty is located (Marks et al., 2020; Sanchez et al., 2020). Only 19% of the rural population in Sub-Saharan Africa has access to safe water (Chen, 2001; Kuczera & Diment, 1988; Rathnayaka et al., 2016; Sorenson et al., 2011; Vuorinen et al., 2007), and Bushenyi District reflects this trend, with 64% of the population reporting unsafe water quality (Paul, 2018; Sanchez et al., 2020).

In Ishaka subcounty, only about 68% of household's access piped water provided by the National Water and Sewerage Corporation (NWSC), (Daniel et al., 2020; Geleijnse et al., 2023; Marks et al., 2020). Most residents rely on alternative sources such as protected and unprotected springs and shallow wells, which are frequently contaminated and become unreliable during dry seasons (Marks et al., 2020; Daniel et al., 2020).

2 Material and Method

2.1. Study Area

The geographical scope of this research study will be focused on Ishaka subcounty. Ishaka subcounty is located Bushenyi Ishaka municipality which is a county in the Bushenyi district of western Uganda, situated approximately 350 km south west of the capital city, Kampala(Sanchez et al., 2020).

2.2 Study Population

Kalton (2020) defines study population as the aggregation of elements from which a sample(s) is actually selected. Data for this study will be collected from households, water supply officials, municipal leaders, community leaders and local people businesses in Ishaka subcounty, Bushenyi district. These groups are directly involved in or affected by the water supply and demand dynamics in the area, providing significant findings into the reliability, quality, and challenges of the current water system.

2.3 Sample size determination

Kish Leslie's (1965) sample size formula will be used to determine the sample size. This formula is appropriate when the population size is large and variable, and when limited prior prevalence data is available (Kish, 1965; Charan & Biswas, 2013).

For the qualitative aspect of the study, purposive sampling will be employed to select individuals who hold critical insights into water supply and demand issues in Ishaka subcounty. This sampling technique ensures that the perspectives gathered are both relevant and insightful (Palinkas et al., 2015).

Determination of the sample size

n= $Z^2 \frac{1-P}{\delta^2}$

Where n= sample size estimate of the population affected by water supply and demand dynamics in Ishaka subcounty

p= Assumed true population affected by water supply challenges, so P = 50.0%

q = 1-P = The probability of not being affected by water supply challenges, so 1-0.5 = 0.5 = 50%

δ = Absolute error between the estimated and true population prevalence of 5%.

The calculated sample size n = 1.962 $\frac{(0.5\times\ 0.5)}{0.052}$

n = $\frac{3.8416\times\ 0.25}{0.0025}$

n = $\frac{0.9604}{0.0025}$

n = 384.16

n is approximately equal to 384

For the qualitative element of the study, a purposive sampling technique will be employed to ensure that participants who can provide in-depth perceptions are selected. This approach is anticipated to allow for the selection of individuals with specific knowledge related to the water supply and demand challenges in Ishaka subcounty. The key informant interviews will be conducted with individuals who have specialized knowledge or positions that give them a unique perspective on the topic. These informants will include municipal leaders, water supply managers, and technical staff involved in the water supply system.

2.4 Data collection methods

2.4.1 Questionnaires

Structured questionnaires was employed to gather quantitative data from households, and local businesses within Ishaka Subcounty. These tools provided information on reliability issues. The questionnaires were designed to collect both numerical data and categorical responses, allowing for statistical analysis and pattern identification.

2.4.2 Key Informative Interviews

Interviews was conducted with municipal leaders, water supply managers, community leaders, and technical staff. These interviews provided insights into the operational, financial, and managerial aspects of the water supply system. Open-ended questions encouragde detailed responses and allow for the exploration of underlying challenges and potential solutions.

2.5 Sources of data

2.5.1 Primary data

Primary data refers to first-hand information that is directly collected to address the research problem (Ajayi, 2017). For this study, primary data gathered through community and technical places visits at Ishaka Subcounty. The researcher engaged directly with respondents after obtaining an introductory letter from the university. Primary data collection methods included interviews and questionnaires. This approach ensured the collection of relevant and specific data regarding water supply reliability.

2.5.2 Secondary data

Secondary data will be sourced from existing records and reports related to the water supply system in Ishaka Subcounty. This will include municipal reports, water supply project documentation, and official statistics from the local water authority. Key data points will encompass information on water production, consumption rates, supply coverage, and historical trends. Additionally, technical reports and policy documents will provide findings into the operational challenges and strategies previously employed to manage water supply and demand in the region.

3 RESULTS

3.1 Water Demand Projection

This section presents results related to the current and projected water demand patterns in the subcounty. Trend analysis was used to assess the current demand patterns and project future water demand whereas time series data was adopted to identify significant patterns and estimate future consumption rates (10 years) based on population growth and urbanization trends.

Table 1
Results from descriptive analysis Secondary data from NWSC

Year	Annual Water Usage (Litres)	Population
2020	246,539,250	15,010
2021	248,765,000	15,100
2022	250,120,500	15,180
2023	251,780,000	15,300
2024	252,945,000	15,400

The results presented in Table 1 showing the annual water usage and population for the period 2020–2024 reveal a consistent increase in both variables over the five-year period. The total population of the subcounty increased from 15,010 in 2020 to 15,400 in 2024, representing an approximate annual growth rate of 2.5%. This population rise directly influences the corresponding increase in annual water consumption, which grew from 246.54 million litres in 2020 to 252.95 million litres in 2024.

The observed trend demonstrates a strong positive correlation between population growth and water demand. As more households are established and economic activities expand, the total volume of water required for domestic, institutional, and small-scale industrial uses naturally rises. This aligns with findings by UBOS (2022) and Bushenyi District Water Office (2023), which report that population growth and urbanization remain major drivers of increasing water demand in small towns and municipal subcounty across Uganda.

Although the rate of increase in water usage appears moderate, it highlights a steady upward trajectory that could stress the existing water supply systems if not addressed through effective planning and infrastructure expansion. The data further indicate that the rise in demand is largely population-driven rather than due to significant changes in per capita consumption, suggesting that the average household water use has remained relatively stable during this period.

These findings form the basis for projecting future water demand using time series models such as ARIMA (0,1,0). Such projections enable planners to anticipate future shortages and design appropriate interventions, including network rehabilitation, additional boreholes, or expansion of NWSC service coverage. The upward trend also underscores the importance of promoting water conservation practices and efficient resource management, especially as Ishaka continues to urbanize.

In regards with the results presented in Fig. 2, the line chart clearly illustrates a steady upward trajectory in annual water usage from the year 2020 to 2024. The gradual incline suggests a consistent year-on-year increase in water demand, with no significant fluctuations or declines during this period. This pattern reflects stable growth in water consumption within the Subcounty. Considering the study results, the progression of the line indicates that the rate of water demand is rising moderately, which likely corresponds to population increases and expanding socio-economic activities in the area.

3.1.1 Results from time series analysis

Table 2
Model Description

			Model Type
Model ID	Annual usage (L)	Model_1	ARIMA (0,1,0)

This model type suggests that water demand follows a non-stationary trend that becomes stable after first-order differencing, meaning the annual increase in water demand is relatively consistent over time. The lack of autoregressive or moving average components (p = 0, q = 0) indicates that past levels or error terms do not significantly affect future demand, reinforcing that the primary driver is a steady upward trend.

In regard with the study objective, which aimed to determine the current and projected water demand patterns in Ishaka subcounty, the ARIMA (0,1,0) model provides evidence of a systematic and predictable growth in water usage. This aligns with underlying population growth and urbanization trends in the area. The model is thus reliable for short- to medium-term forecasting, enabling planners and policymakers to anticipate future demand and align infrastructure development accordingly.

Tale 3: Model Fitness

Fit Statistic	Mean	SE	Minimum	Maximum	Percentile					
					5	10	25	50	75	90
Stationary R-squared	.000	.	.000	.000	.000	.000	.000	.000	.000	.000
R-squared	.999	.	.999	.999	.999	.999	.999	.999	.999	.999
RMSE	82125.000	.	82125.000	82125.000	82125.000	82125.000	82125.000	82125.000	82125.000	82125.000
MAPE	.025	.	.025	.025	.025	.025	.025	.025	.025	.025
MaxAPE	.050	.	.050	.050	.050	.050	.050	.050	.050	.050
MAE	61593.750	.	61593.750	61593.750	61593.750	61593.750	61593.750	61593.750	61593.750	61593.750
MaxAE	123187.500	.	123187.500	123187.500	123187.500	123187.500	123187.500	123187.500	123187.500	123187.50
Normalized BIC	22.979	.	22.979	22.979	22.979	22.979	22.979	22.979	22.979	22.979

From the results presented in Table 3, the model fit statistics indicate that the ARIMA (0,1,0) model provides an excellent and highly reliable fit for forecasting annual water usage in Ishaka subcounty. The R-squared value of 0.999 shows that the model explains nearly 100% of the variation in the observed data, confirming its accuracy and predictive strength. While the Stationary R-squared is 0.000, this is expected for a first-differenced model and does not diminish the model's effectiveness. The Root Mean Squared Error (RMSE) of 82,125 litters and Mean Absolute Error (MAE) of 61,593.75 litters suggest that the average forecast error is very low relative to total annual demand, which is in the range of hundreds of millions of litters. Additionally, the Mean Absolute Percentage Error (MAPE) of 2.5% and a maximum error percentage (MaxAPE) of only 5% further confirm that the model predictions are highly precise. The Normalized BIC value of 22.979 reflects a good balance between model fit and simplicity. Considering the study objective, these results validate the model's strength in accurately capturing current water demand patterns and projecting future demand, thereby providing a solid basis for data-driven planning and water resource management in Ishaka subcounty.

In regards with the observed data (2020–2024), the red line in the graph shows a steady increase in annual water usage, rising from approximately 2.46×10^8 litters in 2020 to over 2.52×10^8 litters in 2024 as shown in Fig. 3. This upward trend reflects growing water demand, likely driven by factors such as population growth, urbanization, and increased domestic, commercial, and institutional usage. The consistent slope of the observed data suggests a relatively predictable pattern of rising consumption.

Considering the study results from 2025 onward, the blue line represents forecasted water demand based on the ARIMA (0,1,0) model. The trend continues upward, maintaining the same steady trajectory as the observed data. This projection indicates that annual water demand is expected to grow linearly, reaching approximately 2.7×10^8 litters by 2034. The absence of abrupt shifts or fluctuations in the forecast line reinforces the assumption of stable growth conditions in the municipality over the next decade.

From the results illustrated in the Fig. 3, it is evident that the water demand pattern in Ishaka Subcounty is increasing gradually and consistently. The close alignment between the end of observed values and the beginning of the forecasted series shows that the model accurately captures existing trends and extends them into the future with confidence. This provides a reliable basis for planning future water supply infrastructure, service expansion, and resource allocation.

3.2 Evaluating the operational reliability of the water supply system in Ishaka subcounty

3.2.1 Main water source

According to the study results, the majority of respondents (75.0%) relied on piped water supply provided by the National Water and Sewerage Corporation (NWSC) as their main source of water, highlighting its central role in meeting domestic needs across Ishaka Subcounty. As shown in Table 4 this was followed by 7.3% who depended on boreholes, 7.0% who relied on rainwater harvesting, 5.8% who accessed water from wells, and 4.9% who used spring water. These findings indicate that although NWSC piped supply remains the dominant source, a notable share of residents still depend on alternative sources such as boreholes, springs, rainwater, and wells reflecting persistent gaps in accessibility and reliability of the water supply network across the subcounty.

Table 4
Main water source of the respondents

Source	Frequency	Percent
Borehole	28	7.3
Spring	19	4.9
NWSC	288	75.0
Rainwater	27	7.0
Well	22	5.8
Total	384	100.0

3.2.2 Reliability of the main water source

From the results, 48.2% of respondents rated their main water source as very reliable, indicating high satisfaction with the consistency of water access in Ishaka Subcounty. Figure 4 illustrates this pattern, showing that 29% considered their source somewhat reliable, while 15% viewed it as unreliable, and only 7.8% described it as completely unreliable. These findings suggest that although the majority of residents trust their water supply, a small proportion still experiences occasional interruptions. This aligns with interview insights from an NWSC official, who noted:

We are pleased that most residents find the water supply very reliable. However, we acknowledge that a few still face challenges due to factors like old pipes and occasional power outages. We are working on upgrades to improve reliability across Ishaka Subcounty.

3.2.3 Daily working hours of main source of water

Based on the results, the average number of hours per day that water was available from respondents' main sources was approximately 18.9 hours, with a standard deviation of 5.34. This indicates that, on average, residents in Ishaka Subcounty had access to water for most of the day, though variability existed across households and locations. As shown in Table 5 the minimum reported duration of water availability was 2 hours per day, while the maximum reached 24 hours, reflecting disparities in supply reliability among different areas or systems. These findings highlight that although the overall supply duration was relatively high, not all residents enjoyed consistent, full-day access to water.

Table 5
Daily working hours of main source of water

	N	Minimum	Maximum	Mean	Std. Deviation
How many hours per day is water available from your main source?	384	2.00	24.00	18.8958	5.33715
Valid N (listwise)	384				

3.2.4 Infrastructure Efficiency

3.2.4.1 Classification of current water infrastructure as per performance

In regard to the study results, the majority of respondents (49.9%) rated the current water infrastructure in their area as efficient, reflecting strong confidence in its functionality and reliability. As presented in Table 6, 26.6% considered the system somewhat efficient, suggesting that while performance is generally good, some operational gaps remain. Only 23.5% described the infrastructure as inefficient, indicating that challenges exist but affect a relatively small portion of households. Overall, these findings suggest that the water infrastructure in Ishaka Subcounty is largely perceived as effective and dependable. while an officers noted that there are leakages "*This is a known challenge for many water utilities worldwide, and we are proactively and transparently addressing it. Our technical teams are actively engaged in detection and repair efforts across our service areas to minimize water loss and ensure reliable supply to our customers*".

Table 6
Rate of current water infrastructure

Response		Frequency	Percent
Valid	Very efficient	230	49.9
	Somewhat efficient	102	26.6
	Inefficient	52	23.5
	Total	**384**	**100.0**
Source: primary data			

3.2.5 How often do Ishaka residents experience water service interruptions

In relation to the study results, 49.7% of respondents reported experiencing monthly water service interruptions, indicating that periodic disruptions are common in Ishaka Subcounty. Figure 5: *Frequency of Water Service Interruptions in Ishaka Subcounty* (Source: Field Survey, 2024) illustrates this trend,

showing that 38.8% of respondents rarely or never experienced interruptions, suggesting a relatively stable supply for many households. Meanwhile, 11.2% reported weekly disruptions, and only 0.3% experienced daily interruptions. These findings demonstrate that while most residents enjoy a fairly consistent water supply, nearly half still face recurrent interruptions, reflecting ongoing challenges in maintaining uninterrupted service. This aligns with an NWSC official's remark: *"We acknowledge that many residents experience monthly water interruptions. These are mainly due to routine maintenance, power outages, and system upgrades. We are working to minimize these disruptions and improve consistency in supply."*

3.2.6 Technological Integration

3 .2.6.1 Are there any technologies used for monitoring or managing water supply (e.g., meters, apps)

From the study results, 83.9% of respondents indicated that technologies such as meters or Yaka (Meter that is used for electricity pill for pumping sources)were used to monitor or manage the water supply, suggesting a high level of technological adoption in water service delivery within Ishaka Subcounty. Figure 6, illustrates this distribution, showing that only 16.1% of respondents reported the absence of such technologies, indicating areas where traditional or manual systems are still in use. These findings reflect a generally modernized approach to water management across the municipality, although minor gaps in technological coverage remain. This aligns with a statement from an NWSC official, who noted:

We have implemented technologies like prepaid meters and digital monitoring systems in most parts of Ishaka Subcounty. However, a few areas still rely on manual systems, which we plan to upgrade as part of our ongoing service improvements.

3.2.7 How effective are these technologies in improving water services
According to the results, the majority of respondents (70.0%) rated the technologies used in managing water supply as very effective, indicating that these tools significantly enhanced service delivery and reliability in Ishaka Subcounty. Table 7 illustrates this distribution, showing that 25.0% of respondents considered the technologies moderately effective, while only 5.0% viewed them as not effective. These findings demonstrate a generally positive perception of technological effectiveness, suggesting that most residents acknowledged the substantial benefits brought by technology in improving water supply management across the subcounty.

Table 7
Effectiveness of technologies in improving water services

Response		Frequency	Percent
Valid	Not effective	19	5.0%
	Moderately effective	96	25.0%
	Very effective	269	70.0%
	Total	384	100.0

3.2.8 Institutional and Governance Factors
3.2.8.1 How satisfied are the residents with the local authorities' role in water supply management
From the results, the overwhelming majority of respondents (88.5%) expressed satisfaction with the role played by local authorities in managing the water supply, reflecting a strong positive perception of their performance in service delivery within Ishaka Subcounty. Figure 7 illustrates this trend, showing that 8.0% of respondents were dissatisfied, while a smaller proportion (3.5%) reported being very dissatisfied. These findings indicate that residents generally hold local authorities in high regard for their efforts in water supply management, though continued improvements and responsiveness to community needs would further strengthen public confidence.

3.2.8.2 Are There clear policies or regulations for water supply
In relation to the study findings, the vast majority of respondents (85.7%) indicated that there were clear policies or regulations governing water supply in their area, suggesting that most residents recognized the existence of formal frameworks guiding water management in Ishaka Municipality. Table 8: presents these findings, showing that only 14.3% of respondents reported the absence of such policies or were unaware of them, indicating a small portion of the population with limited knowledge of governance structures. Overall, the results reflect strong awareness of water supply policies across the subcounty, though continued sensitization could help close the remaining gap. This was in line with the interview findings where one of the officials from NWSC mentioned that:

"There are established policies and regulations guiding water supply, but we recognize that not all residents are aware of them. We are working on improving public awareness through community sensitization and stakeholder engagement."

Table 8
Community Awareness of Water Supply Policies and Regulations

Response		Frequency	Percent
Valid	Yes	329	85.7%
	No	55	14.3%
	Total	**384**	**100.0**

3.2.9 Water Demand Factors

According to the study results, 63.3% of respondents reported living in households with 5 to 8 people, indicating that medium-sized families were the most common in Ishaka Subcounty. Table 9 presents these findings, showing that 20.6% of respondents lived in smaller households of 1 to 4 members, while 16.1% resided in larger households with more than 12 people. These results suggest that most households had moderate family sizes, which could influence water demand and consumption patterns within the subcounty.

Table 9
How many people currently live in each household

Number of people		Frequency	Percent
Valid	1–4	79	20.6
	5–8	243	63.3
	Above 12	62	16.1
	Total	384	100.0
Source: primary data			

3.2.9 Household size changes in the past 5 years?

Study findings showed that the majority (64.1%) of respondents stated that their household size had remained the same over the past five years, indicating stability in family composition for most residents in Ishaka Subcounty. Table 10 presents these results, showing that 35.9% of respondents reported an increase in household size, suggesting growth due to factors such as births, extended family members joining, or other demographic dynamics. Overall, the findings highlight that while most households remained constant in size, a considerable number of experienced changes that may affect water consumption patterns and domestic needs.

Table 10
Changes in Household Size Over the Past Five Years in Ishaka Subcounty presents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Increased	138	35.9	35.9	35.9
	Remained the same	246	64.1	64.1	100.0
	Total	384	100.0	100.0	

3.2.10 Sectoral Water Consumption Patterns

According to the results, the majority (85%) of respondents indicated that their primary use of water was for domestic purposes, showing that household activities such as cooking, cleaning, and bathing were the main drivers of water demand in Ishaka Subcounty. Table 11 presents these findings, showing that 15% of respondents primarily used water for commercial activities, reflecting a portion of the population engaged in business operations such as small-scale industries or service activities. These results highlight the dual nature of water usage in the area, with domestic needs significantly outweighing commercial demands.

Table 11
What is your primary use of water?

Primary use of water		Frequency	Percent
Valid	Domestic	326	85%
	Commercial	58	15%
	Total	**384**	**100.0**
Source: Primary data			

3.2.10 Average Water Usage per Household per day

The study findings showed that the average daily water usage per household in Ishaka Subcounty was approximately 160.7 Liters, with a standard deviation of 61.68 liters. Table 12 summarizes these results, showing that the minimum daily water usage was 60 liters, while the maximum reached 230 liters. These findings suggest that, on average, households consumed a moderate volume of water daily, though notable variations existed likely influenced by household size, purpose of use (domestic or commercial), and access to water sources.

Table 12
On average household use per day

	N	Minimum	Maximum	Mean	Std. Deviation
On average, how much water does your household use per day?	384	60.00	430.00	160.6771	61.68276
Valid N (listwise)	384				

The study findings showed that the average daily water usage per household in Ishaka Subcounty was approximately 160.7 liters, with a standard deviation of 61.68 liters. The minimum amount of water used per day was 60 liters, while the maximum was 430 liters. These findings suggested that, on average,

households consumed a moderate volume of water daily, though there were notable variations in usage levels, likely influenced by household size, purpose of use (domestic or commercial), and access to water sources.

3.2.11 Pricing and Affordability

The results indicate that monthly water expenditure among households in Ishaka Subcounty varies considerably. Figure 8 shows that the majority of respondents (47.9%) reported paying between UGX 18,000–50,000, representing the most common expenditure range. This was followed by 36.7% who spent between UGX 100,001–150,000, and 12.8% who paid UGX 50,001–100,000 per month. Only 2.6% of households reported paying below UGX 18,000. In addition, 25% of respondents indicated that they do not pay for water, as they rely on free or community-managed sources such as rainwater harvesting, protected springs, or private wells.

These findings highlight variations in affordability and access across the subcounty. While most residents contribute financially to NWSC water services, a notable portion continues to depend on non-commercial sources due to limited coverage, income constraints, or geographical barriers.

Conclusion

With regard to the operational reliability of the water supply, the research revealed that water service in the Subcounty is irregular and often inadequate. Some households reported limited hours of supply and interruptions that force them to supplement with alternative sources such as protected or unprotected springs, shallow wells, or rainwater harvesting. While these sources provide relief, they are not always safe or sustainable. The study also noted that service reliability differs between urban and peri-urban areas, with some parts of the subcounty experiencing more consistent supply than others. This unevenness reflects the challenges of expanding coverage to meet growing population needs while maintaining stable service delivery. It also underscores the need to invest in upgrading infrastructure and adopting more resilient water supply strategies that can withstand both seasonal variability and population growth pressures.

The analysis confirmed that water consumption in Ishaka Subcounty is steadily increasing, closely linked to demographic growth and socio-economic development. Time series modelling using ARIMA (0,1,0) demonstrated a consistent upward trend in annual water usage, projecting that demand will continue to rise over the coming decade. This means that without timely planning and expansion of infrastructure, the gap between available supply and household demand is likely to widen further. The implication is that current infrastructure and management approaches, while providing partial coverage, may not be sufficient to cope with future needs. This calls for long-term planning that integrates demand forecasts into investment decisions and policy frameworks.

Declarations

Acknowledgement

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We declare that the dataset used for analysis in this work is original and unique

Authors Contribution

Ahmed Abdirizak Dirie and Abdulkadir Ahmed Mohamed: Research topic review and conceptualization, research gap analysis and writing, Prof. K. Deepa: Supervision and editing, Farhan Adan Nur and Abdishakur Abshir Mohamed: Literature review and technical support.

Funding

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Data availability

The data are available on request from the authors.

Conflict of interest

The author declares that there were no competing interests.

Ethical approval

The protocol was approved by Kampala International University Research Ethics Committee (KIU-REC) at Western Campus. The approval was granted under reference number KIU-2025-1721.the approval document can be attached if it is requested by the editors or other journal admins.

All procedures performed were in accordance with the ethical standards of Kampala International University Research Ethics Committee (REC).

Clinical trial number

Clinical trial number is not applicable for this research.

Consent to Participate Declarations

Informed consent was obtained from all individual participants involved in this study. Prior to participation, the purpose of the study, procedures, potential risks, and benefits were fully explained. Participants were assured of the confidentiality of their responses and that their participation would not result in any negative consequences. This assurance was provided to promote voluntary and ethical engagement in the research.

Consent to Publish declarations

Not applicable

References

1. Abellán, J. (2017). *XII INTERNATIONAL CONGRESS OF THE SPANISH potable y saneamiento en Europa : siglos XIX y XX Water supply and sanitation services in modern Europe : Water supply and sanitation services in modern Europe : developments in 19 th -20 th centuries*. *September*, 6–9.
2. Amit, R. K., & Sasidharan, S. (2019). Measuring affordability of access to clean water: A coping cost approach. *Resources, Conservation and Recycling*, *141*(December 2017), 410–417. https://doi.org/10.1016/j.resconrec.2018.11.003
3. Baba, A. (2018). Developments in water dams and water harvesting systems throughout history in different civilizations. *International Journal of Hydrology*, *2*(2), 150–166. https://doi.org/10.15406/ijh.2018.02.00064
4. Bailey, E. S., Beetsch, N., Wait, D. A., Oza, H. H., Ronnie, N., & Sobsey, M. D. (2021). Methods, protocols, guidance and standards for performance evaluation for point-of-use water treatment technologies: History, current status, future needs and directions. *Water (Switzerland)*, *13*(8), 1–85. https://doi.org/10.3390/w13081094
5. Bartram, J., Brocklehurst, C., Fisher, M. B., Luyendijk, R., Hossain, R., Wardlaw, T., & Gordon, B. (2014). Global monitoring of water supply and sanitation: History, methods and future challenges. *International Journal of Environmental Research and Public Health*, *11*(8), 8137–8165. https://doi.org/10.3390/ijerph110808137
6. Bwire, G., Sack, D. A., Kagirita, A., Obala, T., Debes, A. K., Ram, M., Komakech, H., George, C. M., & Orach, C. G. (2020). The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera prone communities of Uganda: an analysis of vital physicochemical parameters. *BMC Public Health*, *20*(1), 1–18. https://doi.org/10.1186/s12889-020-09186-3
7. Capone, J. A., & Marston, L. T. (2025). Water Demand Projection Accuracy and Demand Management Trends in California Cities. *Water Resources Research*, *61*(11). https://doi.org/10.1029/2025WR040474
8. Chen, Y. D. (2001). Sustainable development and management of water resources for Urban water supply in Hong Kong. *Water International*, *26*(1), 119–128. https://doi.org/10.1080/02508060108686891
9. Daniel, D., Gaicugi, J., King, R., Marks, S. J., & Ferrero, G. (2020). Combining sanitary inspection and water quality data in western Uganda: Lessons learned from a field trial of original and revised sanitary inspection forms. *Resources*, *9*(12), 1–19. https://doi.org/10.3390/resources9120150
10. Geleijnse, J., Rutten, M., de Villiers, D., Bamwenda, J. T., & Abraham, E. (2023). Enhancing water access monitoring through mapping multi-source usage and disaggregated geographic inequalities with machine learning and surveys. *Scientific Reports*, *13*(1), 1–23. https://doi.org/10.1038/s41598-023-39917-6
11. Gendeshmin, S. B., Seyedin, S. H., & Dowlati, M. (2025). Drinking water supply for communities affected by natural disaster emergencies: a qualitative study. *BMC Emergency Medicine*, *25*(1). https://doi.org/10.1186/s12873-025-01225-9
12. Hermelink, M. I., Pittore, K. H., Álvarez Aranguiz, A., Pereira da Silva, F. I., Roefs, M. M. I., Kajobe, R., Malingumu, R., & Hengsdijk, H. (2023). A healthy diet for a growing population: a case study of Arua, Uganda. *Food Security*, *15*(3), 773–789. https://doi.org/10.1007/s12571-022-01337-1
13. Kanyesigye, C., Kulabako, R. N., Kalibbala, M., Niwagaba, C. B., Babu, M., Boller, M., & Kansiime, F. (2024). *Processes Controlling pH in Nyaruzinga Wetland Source and the Water Supply System in Bushenyi-Ishaka Municipality, Uganda*. *12*.
14. Kanyesigye, C., Twesigye, I., Marks, S. J., Niwagaba, C. B., Kulabako, R. N., Ferrero, G., & Kansiime, F. (2023). Assessment of risks to the quality of water supplied in Bushenyi-Uganda using the water safety plan approach. *Water Practice and Technology*, *18*(12), 2989–3003. https://doi.org/10.2166/wpt.2023.193
15. Kuczera, G., & Diment, G. (1988). General Water Supply System Simulation Model: WASP. *Journal of Water Resources Planning and Management*, *114*(4), 365–382. https://doi.org/10.1061/(asce)0733-9496(1988)114:4(365)
16. Mala-Jetmarova, H., Barton, A., & Bagirov, A. (2015). A history of Water distribution systems and their optimisation. *Water Science and Technology: Water Supply*, *15*(2), 224–235. https://doi.org/10.2166/ws.2014.115
17. Marks, S. J., Clair-Caliot, G., Taing, L., Bamwenda, J. T., Kanyesigye, C., Rwendeire, N. E., Kemerink-Seyoum, J. S., Kansiime, F., Batega, D. W., & Ferrero, G. (2020). Water supply and sanitation services in small towns in rural–urban transition zones: The case of Bushenyi-Ishaka Municipality, Uganda. *Npj Clean Water*, *3*(1), 1–9. https://doi.org/10.1038/s41545-020-0068-4
18. Mugumya, T., Isunju, J. B., Ssekamatte, T., Wafula, S. T., & Mugambe, R. K. (2020). Factors associated with adherence to safe water chain practices among refugees in pagirinya refugee settlement, Northern Uganda. *Journal of Water and Health*, *18*(3), 398–408. https://doi.org/10.2166/wh.2020.230
19. Musoke, D., Ndejjo, R., Halage, A. A., Kasasa, S., Ssempebwa, J. C., & Carpenter, D. O. (2018). Drinking Water Supply, Sanitation, and Hygiene Promotion Interventions in Two Slum Communities in Central Uganda. *Journal of Environmental and Public Health*, *2018*. https://doi.org/10.1155/2018/3710120

20. Nyakutsikwa, B. F. (2018). *Analysis of Small Town Sanitation Evaluation of existing services in Bushenyi and a comparison of the enabling environment with a large city*. *March*.
21. Paul, R. (2018). *Water governance in small towns at the rural-urban intersection: the case of Bushenyi-Ishaka, Uganda Sketch Credits: Ramkrishna Paul*. *March*.
22. Rana, P. S., Uniyal, R. S., Chamola, K. P., & Srivastava, A. K. (2024). Optimizing water supply systems in developing regions: a sustainable approach using ESCO model system for urban water supply in Dehradun, India. *Discover Water*, *4*(1). https://doi.org/10.1007/s43832-024-00107-8
23. Rathnayaka, K., Malano, H., & Arora, M. (2016). Assessment of sustainability of urban water supply and demand management options: A comprehensive approach. *Water (Switzerland)*, *8*(12). https://doi.org/10.3390/w8120595
24. Sakomoto, T., Lutaaya, M., & Abraham, E. (2020). Managing water quality in intermittent supply systems: The Case of Mukono Town, Uganda. *Water (Switzerland)*, *12*(3). https://doi.org/10.3390/w12030806
25. Sanchez, L. M. S. N., Kemerink-Seyoum, J. S., Batega, D. W., & Paul, R. (2020). Caught in the middle? Access to water in the rural to urban transformation of Bushenyi-Ishaka municipality, Uganda. *Water Policy*, *22*(4), 670–685. https://doi.org/10.2166/wp.2020.024
26. Sanusi, I. O., Olutona, G. O., Wawata, I. G., & Onohuean, H. (2024). Heavy metals pollution, distribution and associated human health risks in groundwater and surface water: a case of Kampala and Mbarara districts, Uganda. *Discover Water*, *4*(1). https://doi.org/10.1007/s43832-024-00087-9
27. Sorenson, S. B., Morssink, C., & Campos, P. A. (2011). Safe access to safe water in low income countries: Water fetching in current times. *Social Science and Medicine*, *72*(9), 1522–1526. https://doi.org/10.1016/j.socscimed.2011.03.010
28. Tang, S. L. (2000). Dual water supply in hong kong. *Water, Sanitation and Hygiene - Challenges of the Millennium: Proceedings of the 26th WEDC Conference*, 364–366.
29. Vuorinen, H. S., Juuti, P. S., & Katko, T. S. (2007). History of water and health from ancient civilizations to modern times. *Water Science and Technology: Water Supply*, *7*(1), 49–57. https://doi.org/10.2166/ws.2007.006
30. Walekhwa, A. W., Ntaro, M., Kawungezi, P., Nimusiima, E., Achangwa, C., Musoke, D., & Mulogo, E. M. (2022). Water quality of improved water sources and associated factors in Kibuku District, Eastern Uganda. *Sustainable Water Resources Management*, *8*(2), 1–13. https://doi.org/10.1007/s40899-022-00604-5
31. Walton, B., Nawarathna, B., George, B. A., & Malano, H. M. (2009). Future water supply and demand assessment in peri-urban catchments using system dynamics approach. *18th World IMACS Congress and MODSIM 2009 - International Congress on Modelling and Simulation: Interfacing Modelling and Simulation with Mathematical and Computational Sciences, Proceedings*, *July*, 3872–3878.
32. Whittington, D., Davis, J., & McClelland, E. (1998). Implementing a demand-driven approach to community water supply planning: A case study of lugazi, uganda. *Water International*, *23*(3), 134–145. https://doi.org/10.1080/02508069808686760
33. Yue, D. P. T., & Tang, S. L. (2011). Sustainable strategies on water supply management in Hong Kong. *Water and Environment Journal*, *25*(2), 192–199. https://doi.org/10.1111/j.1747-6593.2009.00209.x

Figures

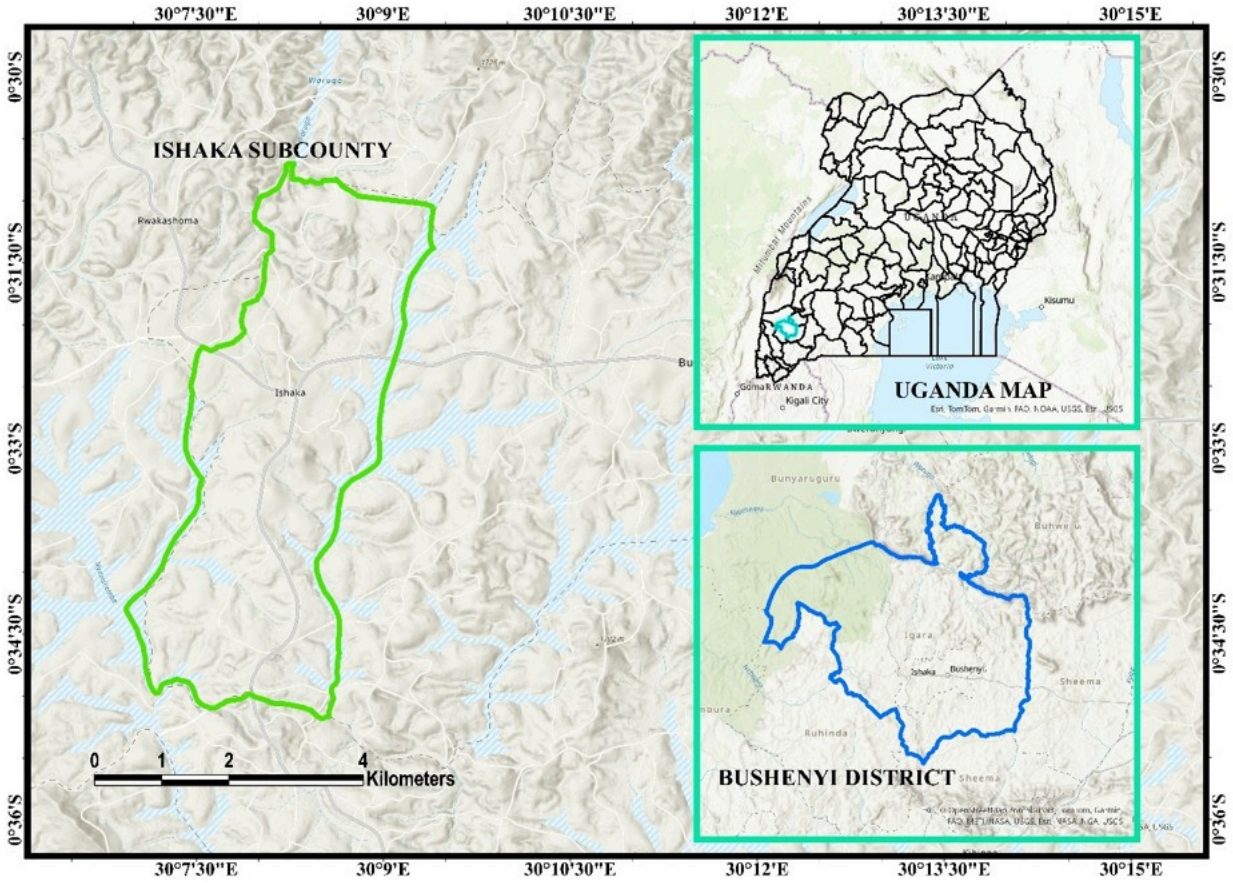


Figure 1

Study Area

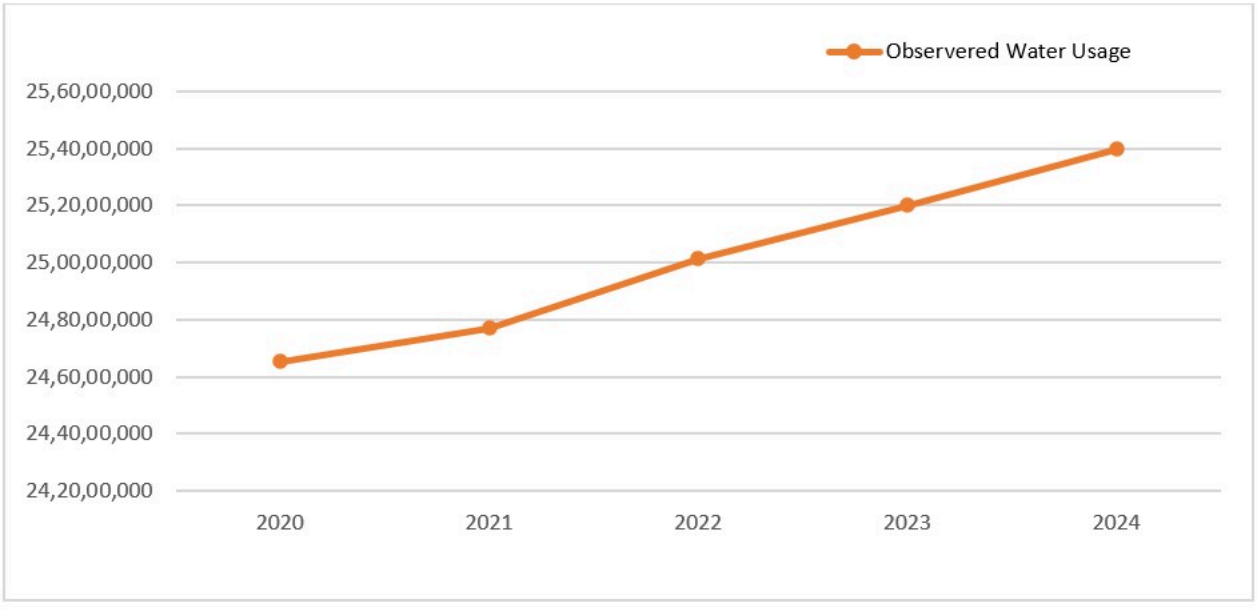


Figure 2

Line chart showing trend of annual water usage from 2020 to 2024

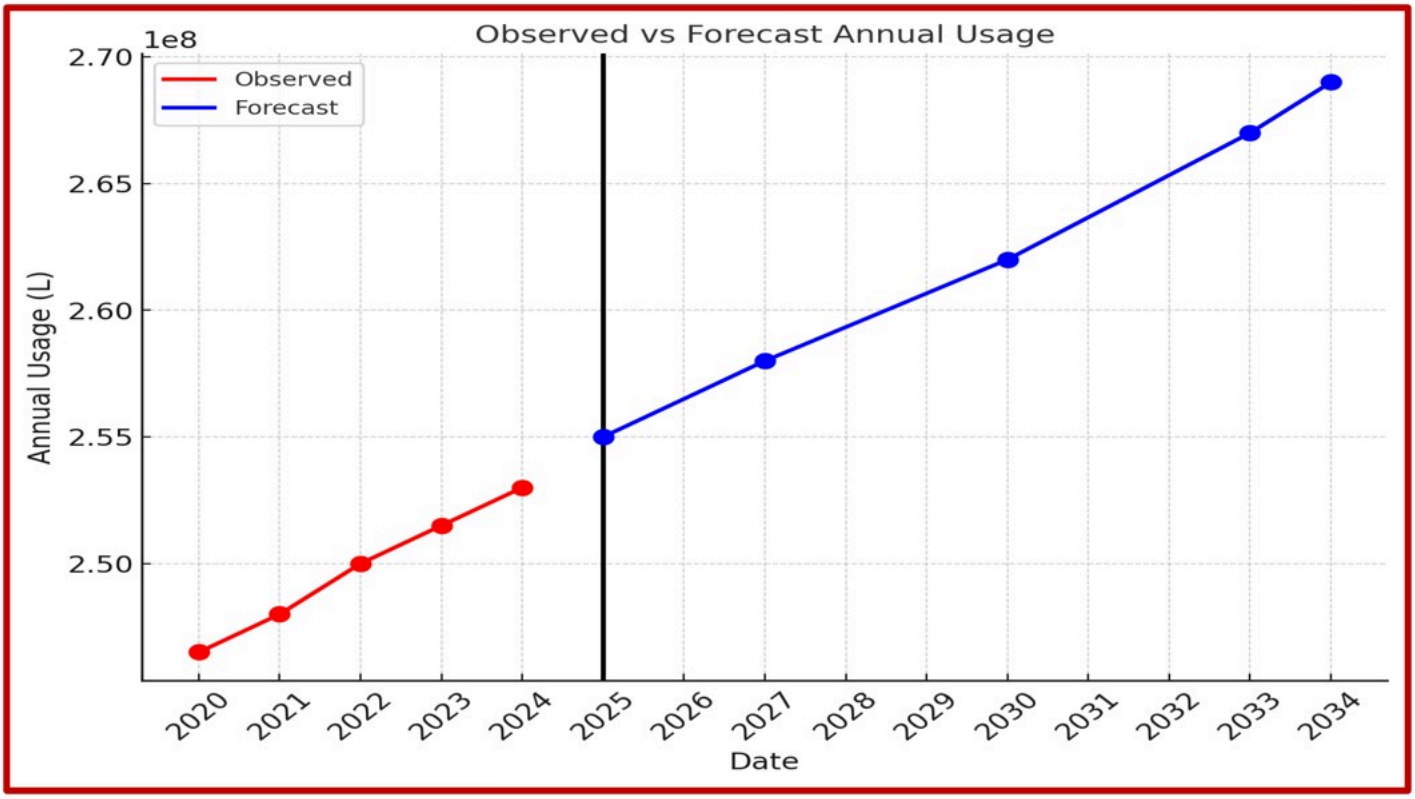


Figure 3

Observed and Forecasted water demand

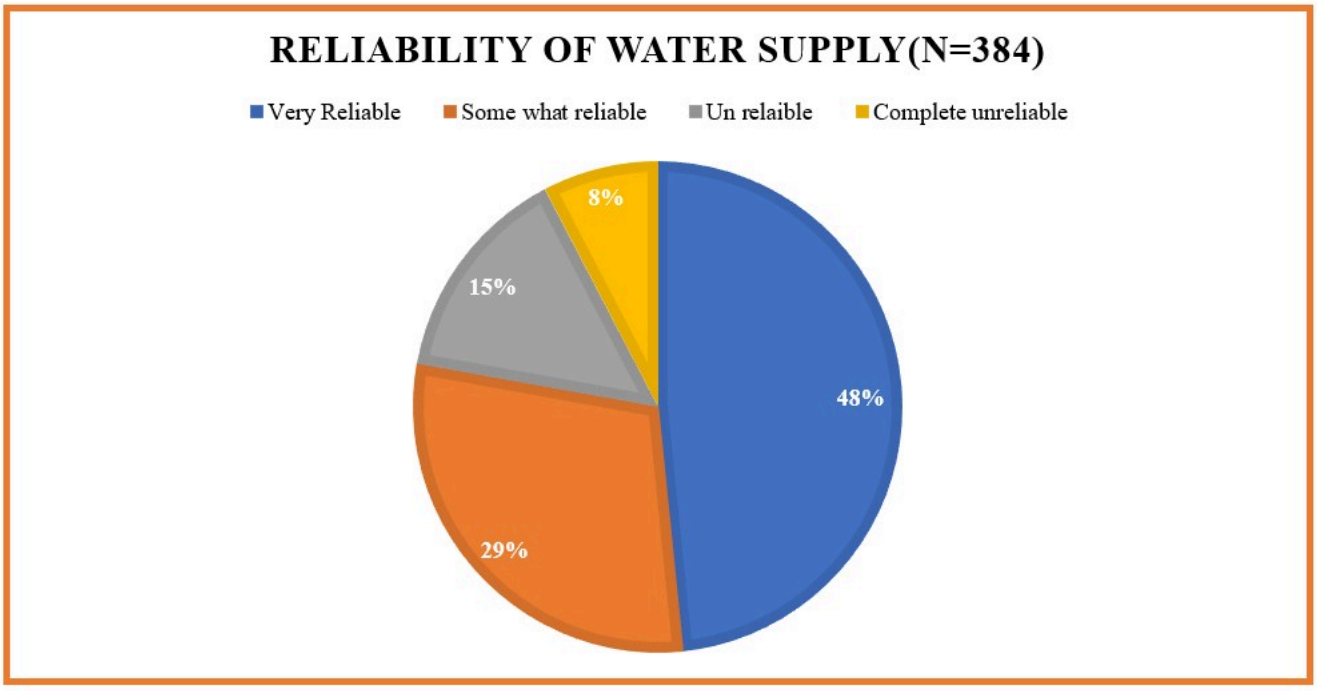


Figure 4

Reliability of the main water source

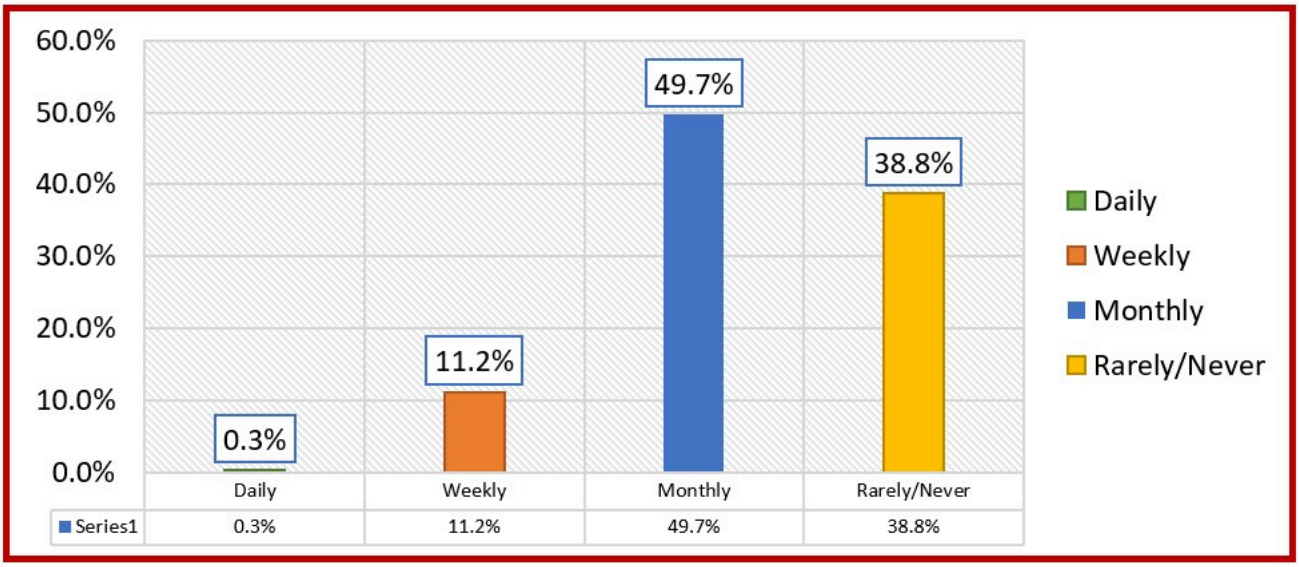


Figure 5

Frequency of water service interruptions

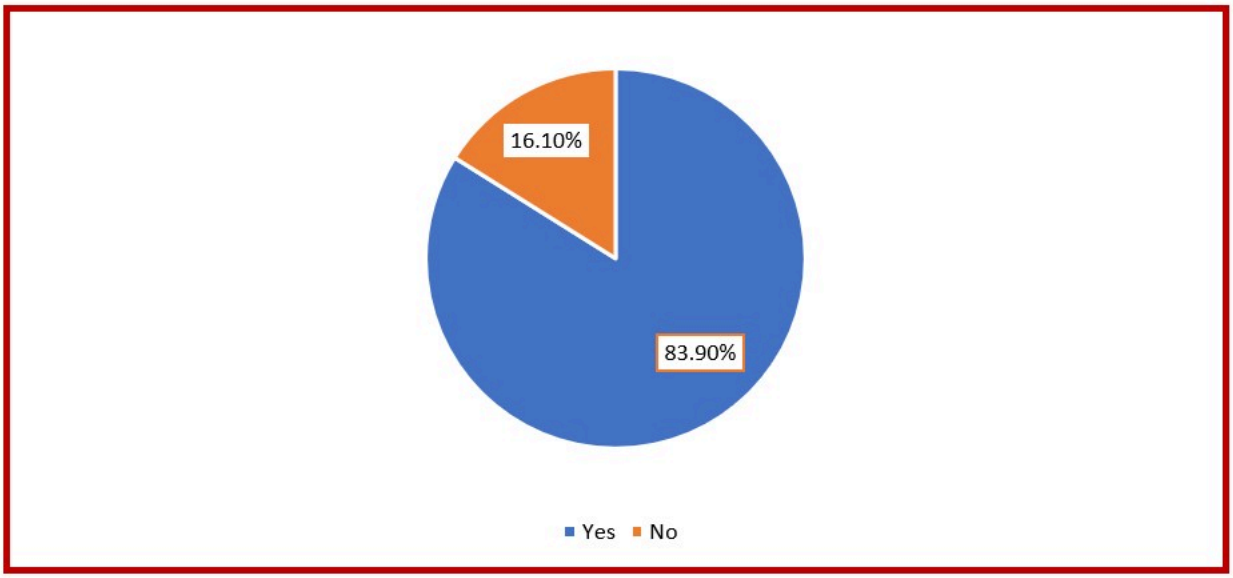


Figure 6

Technological Integration

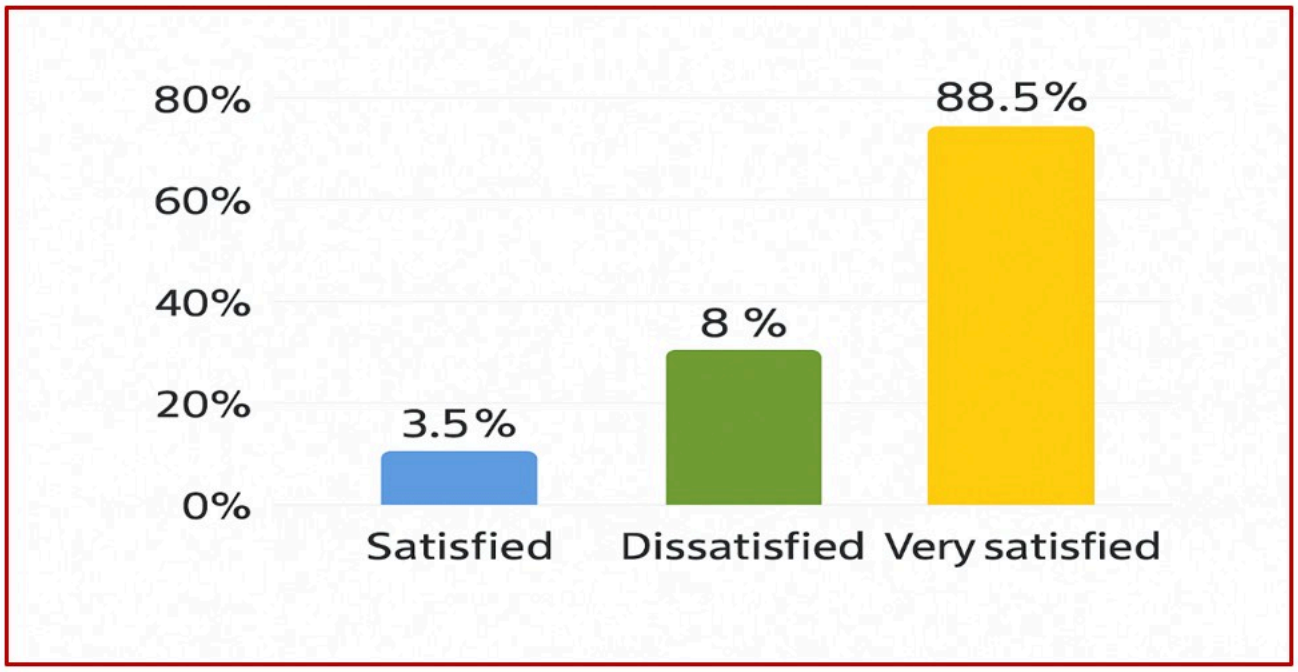


Figure 7

Satisfaction with the Local Authorities' Role in Water Supply Management

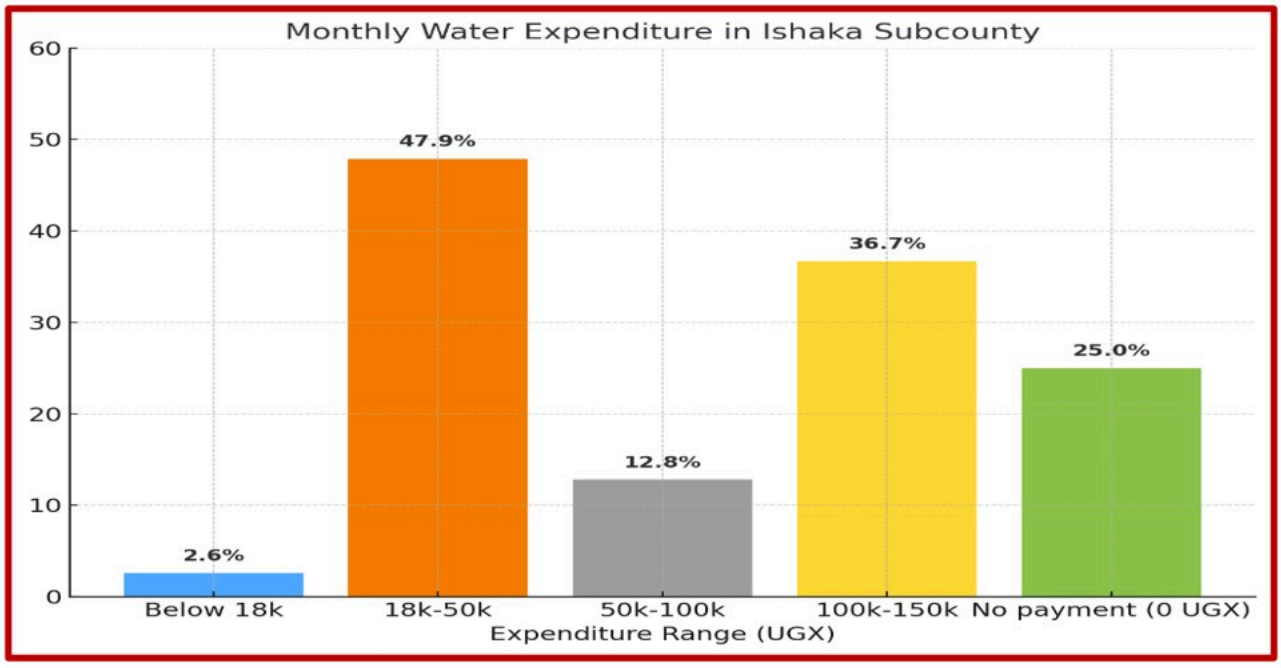


Figure 8

How much do each household pay monthly for water services?

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- APPENDICES.docx