

# Assessment of the Status of Water Supply Chain and Associated Sanitation Interventions Alongside Kivu Lake in Nyamasheke District, Rwanda

<sup>1</sup>Mr. Shukuru Regis, <sup>2</sup>Dr. Celestin BANAMWANA

<sup>1</sup>Author, <sup>2</sup>Co-author

<sup>1</sup>(School of Public Health, Mount Kenya University, Rwanda)

<sup>2</sup>(School of Public Health, Mount Kigali University)

DOI: <https://doi.org/10.5281/zenodo.17207242>

Published Date: 26-September-2025

---

**Abstract:** The study examined access to clean water and related sanitation interventions along Lake Kivu in Nyamasheke District, Rwanda, where water accessibility data is limited. Its objectives were to assess the status and maintenance of the water supply chain, identify sanitation interventions, explore factors influencing water supply chain management, and evaluate household-level water treatment practices. Guided by WASH, Systems, and Sustainable Development theories, the research employed a descriptive cross-sectional design with a quantitative approach. From a target population of 426, a sample of 337 households was selected through multistage sampling, with four of seven villages chosen purposively. Findings revealed that 64.99% of households depended on farming, 56.38% were female-headed, and 57.27% had only primary education. Lake water was a major source, significantly linked to household burden, especially where distances exceeded 500 m or collection times surpassed 60 minutes. Average daily water use was 38.5 liters, and higher consumption correlated with increased strain. Flush toilets improved access, while shared toilets and inadequate handwashing facilities posed health risks. Factors improving water supply chain management included access to piped water, willingness to pay for services, and strong governance structures. Household-level interventions like container cleaning (82.49%), boiling water (48.66%), food-grade storage, and clean storage environments effectively reduced contamination risks. Conversely, poor maintenance awareness and unresolved infrastructure issues were key challenges. The study concludes that expanding piped water infrastructure, strengthening hygiene education, and involving stakeholders such as WASAC, MININFRA, and NGOs are vital for meeting Sustainable Development Goal 6 and ensuring safe, sustainable rural water systems in Nyamasheke District.

**Keywords:** Water Supply Chain, Sanitation, Kivu Lake, Nyamasheke District, Rwanda.

---

## I. INTRODUCTION

Globally, water is crucial for sustaining life, making it imperative to ensure a sufficient, safe, and accessible supply for everyone. Enhancing access to safe drinking water leads to clear health benefits (WHO, 2019). The World Health Organization (WHO, 2019) defines "safe drinking water" as water that poses no significant health risk over a lifetime of consumption (WHO, 2019). According to a WHO report from 2017, biological contamination of water is responsible for 80% of all human diseases in developing countries. Approximately 2.3 billion people worldwide are at risk of waterborne illnesses due to inadequate access to safely managed drinking water and proper sanitation systems. The UNICEF Joint Monitoring Program Report (2000-2017) provides a global overview of water quality improvements, noting a 10% increase in the availability of safely managed drinking water and a 16% increase in safely managed sanitation services worldwide (Shazia and Amar, 2023).

Overseas and inland surface and sub-surface water systems play an incredible role in everyday life activities, especially for drinking and other domestic uses. These influences have led to significant ecological and environmental consequences. Glibert, & Burford (2017) Recent data indicates that access to improved drinking water sources in rural areas of various African countries remains a significant challenge. The DRC only 52% of the population has access to an improved water source, leaving approximately 33 million people in rural areas without quality water. In Mali, while 80% of the overall population has access to improved drinking water sources, this figure drops to 70% in rural areas. In Malawi, 63% of the rural population has access to improved drinking water sources, compared to 87% in urban areas. Additionally, 37% of rural households spend 30 minutes or more fetching drinking water, highlighting the accessibility challenges faced by these communities. In Sudan, only 53% of rural households have improved drinking water sources within a 30-minute walk, with 28% having even more limited access, often relying on polluted water from shallow waterholes or unprotected sources. These statistics underscore the ongoing disparities in access to safe drinking water between urban and rural areas across Africa, emphasizing the need for targeted interventions to improve water infrastructure and accessibility in rural communities (UNICEF, 2023).

Thus far, some African countries have worked to develop reliable water supply systems, Household Water Treatment and Safe Storage (HWTSS) interventions (e.g., filtration, boiling, chemical disinfectants, solar disinfectant, use of covered collection and storage containers) serve as interim options for obtaining safe drinking water in the home. Various HWTSS interventions have been shown effective in reducing diarrheal disease in settings with unsafe drinking water (Vos et al., 2019).

In the baseline year of the sustainable development agenda, 2015, 2.1 billion people lacked safely managed drinking water services globally and 844 million people did not have basic drinking water services (WHO/UNICEF,2017). Around a million hand pumps in rural Africa provide water to approximately 200 million rural Africans but break frequently, wasting billions of dollars of investment (Baumann, 2019; Baumann and Furey,2023), and forcing the poor to regularly use more distant and often dirty water sources. This situation is exacerbated by an increasing frequency of extreme events, including prolonged droughts, exerting additional stress on local water resources (MacDonald and Calow,2019; Taylor et al.,2022; James and Washington,2013; James et al.,2017).

Achieving universal, safely managed and equitable water services (WHO/UNICEF, 2021) for rural water users requires progress in several areas. Often one or more of the requirements for them to be sufficient, safe, affordable, equitable, and universal are not met depending on different management arrangements of water points and diverging risk perceptions of water users. In the above regard, unsafe drinking water remains a leading risk factor for global mortality and morbidity, accounting for at least 1.23 million deaths and 65.1 million disability-adjusted life years (DALYs) from enteric infections in 2019 (Murray, C. J. et al., 2019).

In Africa, about 85% of the disease burden could be prevented through improved WASH. Indeed, through improvements in WASH, 502,000, then 280,000, and then 297,000 deaths due to inadequate drinking water, sanitation, and poor hand hygiene respectively could be averted (Prüss-Ustün et al.,2024). Specifically, interventions aimed at improving water quality have been associated with diarrhea and infectious disease reductions. This notwithstanding, many countries including Uganda are still grappling with challenges related to water access with 663 million people in the world estimated to lack access to improved water supplies, half of whom are in sub-Saharan Africa (WHO/UNICEF, 2021). Therefore, in addition to ensuring access to safe water, similar efforts should be made to ensure that the provided water is of good quality through maintaining the safe water chain. Safe water chain includes all processes involved in ensuring that water is not contaminated through all stages from the water source to consumption. Key stages in the safe water chain include water collection, handling, transportation, storage and treatment, and consumption (Ssemugabo, 2019).

In Rwanda, 82% of households use water from improved drinking water including pipe borne water, protected springs/wells, public tap, tube wells and rainwater. About 18% use water from unimproved sources such as unprotected springs and wells, rivers, and lakes (RPHC5,2022). At the province level, the proportion of private households using water from improved drinking water sources is highest in the City of Kigali at 97% and lowest in the Western Province at 75% (RPHC5,2022). Variation by district is associated with the level of urbanization. Access to improved sources of drinking water is better in most urbanized districts of Kigali City and poorer in the most rural districts of the Western Province where Nyamasheke district makes part with the rate of 73.5% (RPHC5,2022). The main source of water used by private households varies according to the area of residence.

For instance, in urban areas, the main sources of drinking water supply are Boreholes (41%), public tap-out compounds (32%) and the protected spring and well (12%). In contrast, in rural areas, the main sources of water supply are the protected spring and well and public tap out of the compound with (34) % and (33%) respectively and unprotected spring or well (15%). It is therefore this study aimed to assess the factors associated with a safe water supply chain at households of Nyamasheke district in order to improve the life condition of families and its relationship with the occurrence of water-related diseases in the community.

## II. RESEARCH METHODOLOGY

### Research Design

The study adopted the descriptive cross-sectional design with a quantitative approach to assess the safe water supply chain maintenance and associated factors alongside Kivu Lake, in Nyamasheke District. This study was conducted in Nyamasheke district, specifically in Kagano sector which is alongside Kivu Lake.

### Target Population

The population of study were people from households of Kagano sector where the allowed participants were aged between 18 and 65 years both females and males from four villages namely Ninzi, Rugabano, Gikuyu and Gasayo of Kagano sector in Nyamasheke district. According to the fifth Rwanda Population and Housing Census conducted in 2022, the population of Nyamasheke District is 434,221 (Nyamasheke Report, 2022) and Kagano Sector has 39,994. Thus far, the households as target population of the study are respectively 128, 112, 98 and 88 from Ninzi, Rugabano, Gikuyu and Gasayo villages. (SRPHC, 2022). **Sample Design**

### Sample Size

The size of sample was calculated from a total of 337 households of Kagano sector especially in four villages such as Ninzi, Rugabano, Gikuyu, and Gasayo respectively. That is to be found by application of Slovin's formula:  $n=N/(1+Nxe^2)$ . (Slovin, E.,1960).

This formula is interpreted as following:

**n** is the size of sample.

**N** is the households from the area of study.

**e<sup>2</sup>** is the margin of error which has a value of 0.05

**1** is part of the standard formula

Therefore:

Sample Size(n) in Ninzi= $128/(1+128 \times 0.05^2) = 97$

Sample Size(n) in Rugabano= $112/(1+112 \times 0.05^2) = 88$

Sample size(n) in Gikuyu= $98/(1+98 \times 0.05^2) = 79$

Sample size(n) in Gasayo= $88/(1+88 \times 0.05^2) = 72$

**Table 1: Sample size of households from Ninzi, Rugabano, Gikuyu and Gasayo**

Name of village	Households (N)	Sample size (n)
Ninzi	128	97
Rugabano	112	88
Gikuyu	98	79
Rusayo	88	72
<b>Total</b>	<b>426</b>	<b>337</b>

### Sampling Technique

Multiple stage sampling method has to be applied while selecting households of participants. In the first stage, the four out of seven villages are to be selected purposively. The second step is to select the participants for this study where the random sampling method is to be applied in order to answer the questions from questionnaire designed. A total 337 households are to be selected randomly from 426 households of four villages (Ninzi, Rugabano, Gikuyu and Rusayo).

## Data Collection Methods

### Instrument for Data Collection

The pretested questionnaire tool was adopted from the research article with title: “Knowledge and Practices of households on safe water chain maintenance in a slum community in Kampala city, Uganda” done by (Charles, 2019). This were used to collect the actual data. The pre-test has to be carried out in one village close to the four selected villages. The questionnaire is translated format from English into Kinyarwanda language with components like socio-demographic characteristics, information on water sources, knowledge and practices of participants on water supply chain maintenance and associated sanitation interventions as well.

### Data Analysis

Data were managed using SPSS version 27 and analyzed through cross-tabulation, descriptive, and inferential statistics, with findings presented using graphs, histograms, and charts. Three levels of score options can determine the knowledge of respondents where the correct answer got 1, the wrong answer and don't know get 0. All individuals' answers to knowledgeable questions were computed to obtain total mean scores.

The respondents' practices regarding the water supply chain were evaluated using a scoring system where safe practices are assigned a score of 1 and unsafe or incorrect practices are given a score of 0 for each question item. The total mean score of individual answers to these practice questions were calculated. Participants were categorized as having good practices if their scores are equal to or above the mean score, and as having poor practices if their scores are equal to or below the mean score (Chanyalew and Alemayehu, 2017).

The bivariate of safe water chain maintenance “yes” or “no” and other explanatory factors were analyzed. The association were analyzed under multivariate logistic regression using AOR or  $P < 0.05$  In addition, the geographic data were exported in (Arc GIS, V) for analysis and households' water access were calculated and indicated on the Map.

## III. RESEARCH FINDINGS

### 1. Demographic Characteristics of Respondents

The study begins by examining the demographic characteristics of respondents including gender, age, and education level to establish a foundational context for interpreting the findings related to the status of the water supply chain and associated sanitation interventions in Nyamasheke District, particularly along Kivu Lake.

**Table 1: Demographic Characteristics of Respondents**

Category	Sub-Category	Frequency	Percentage (%)
<b>Province</b>	Western Province	337	100.00
<b>District</b>	Nyamasheke District	337	100.00
<b>Sector</b>	Kirimbi	92	27.30
	Shangi	84	24.93
	Bushenge	68	20.18
	Karengera	50	14.84
	Kanjongo	43	12.75
<b>Gender</b>	Male	147	43.62
	Female	190	56.38
<b>Age (years)</b>	<40	98	29.08
	40–60	179	53.11
	>60	60	17.81
<b>Education</b>	Illiterate	91	27.00
	Primary	193	57.27
	Post-primary	53	15.73
<b>Marital Status</b>	Single	42	12.46
	Married	249	73.90
	Divorced	20	5.93
	Widowed	26	7.71

<b>Religion</b>	Christian	291	86.36
	Muslim	33	9.79
	Cultural	13	3.86
<b>Profession</b>	Farmer	219	64.99
	Business person	42	12.46
	Gov't/company employee	31	9.20
	Jobless	26	7.71
	Other (e.g. artisan)	19	5.63
<b>Family Size</b>	<5 members	124	36.80
	>5 members	213	63.20
<b>Total</b>		<b>337</b>	<b>100.00</b>

Source: Primary Data (2025)

The findings presented in Table 1 revealed a consistent demographic distribution of the study participants across various socio-economic and geographical characteristics. All 337 respondents (100%) were drawn from the Western Province, specifically from Nyamasheke District, confirming the geographical focus of the research. Within the district, Kirimbi Sector contributed the highest number of participants (92; 27.30%), followed by Shanghi (84; 24.93%), Bushenge (68; 20.18%), Karengera (50; 14.84%), and Kanjongo (43; 12.75%), reflecting the population density and proximity to Lake Kivu where water supply and sanitation issues are most relevant. Gender distribution. The table additionally showed a slightly higher representation of females (190; 56.38%) compared to males (147; 43.62%), aligning with the roles of women in water collection and domestic sanitation in Rwandan households, as supported by Musabe and Rurangwa (2021), who noted that women are more engaged in managing household water usage in rural Rwanda. The investigation into the age of respondents as indicated by Table 1 found that the majority (179; 53.11%) were between 40–60 years, followed by those below 40 years (98; 29.08%), and those above 60 years (60; 17.81%), suggesting a mature, experienced population capable of offering informed perspectives on long-standing water and sanitation conditions. Education-wise, the findings revealed in Table 2 that most respondents had attained primary education (193; 57.27%), while 91 (27.00%) were illiterate and 53 (15.73%) had post-primary education. This modest education level reflects both challenges and opportunities for community awareness programs and aligns with Mwinuka (2020) who emphasized the role of basic education in adopting sanitation interventions.

As Table 1 showed, 249 respondents (73.90%) were married, indicating the predominance of family-based households. Regarding religion, Table 1 showed that Christianity dominated with 291 respondents (86.36%), followed by Muslims (33; 9.79%) and traditional religions (13; 3.86%), which may influence communal water beliefs and hygiene practices. In terms of occupation, Table 2 revealed that the majority were farmers (219; 64.99%), with others engaged in business (42; 12.46%), government or company jobs (31; 9.20%), unemployed (26; 7.71%), or other minor roles such as artisans (19; 5.63%), suggesting a primarily agrarian economy with variable income levels influencing sanitation access.

Finally, Table 1 showed that most households (213; 63.20%) had more than five members, a critical factor in assessing water demand and waste management, while 124 households (36.80%) had fewer than five members. These findings reflect the broader national family structure trends as highlighted by Rwanda's National Strategy for Transformation (NST1) which emphasizes improving access to water and sanitation in densely populated households. Supporting this, a respondent from Bushenge Sector stated, "Having clean water in a household of eight people is not just a convenience, it is survival for our children's health and dignity." Overall, these socio-demographic characteristics provide a foundation for understanding community-specific water and sanitation needs and support the importance of tailored interventions in policy and program planning.

## 2. Presentation of Findings

This section systematically addressed the study's objectives and research questions by gathering insights from both participants and the researcher.

### 2.1 The Status of Water Supply Chain and its Maintenance Practices alongside Kivu Lake in Nyamasheke District

First, the study aimed to determine the condition and functioning of the water supply chain, including existing maintenance practices, in communities situated alongside Lake Kivu in Nyamasheke District. This involved assessing the reliability, accessibility, and sustainability of water sources serving the local population.

**Table 2: Bivariate and Multivariate Analysis on Status of Water Supply Chain in Kagano Sector**

Variable	Bivariate Analysis OR (95% CI)	p-value	Multivariate Analysis AOR (95% CI)	p-value
<b>Main water source</b>				
Spring (ref)	1.00	—	1.00	—
Lake	1.82 (1.09–3.05)	0.022	1.74 (1.01–3.01)	0.045
Piped water	0.56 (0.32–0.98)	0.042	0.61 (0.34–1.10)	0.098
Other	1.15 (0.53–2.50)	0.722	1.02 (0.45–2.34)	0.957
<b>Distance to water source</b>				
In the compound (ref)	1.00	—	1.00	—
Less than 500 meters	1.67 (1.01–2.78)	0.047	1.59 (0.95–2.66)	0.075
More than 500 meters	3.40 (2.02–5.72)	<0.001	2.95 (1.66–5.24)	<0.001
<b>Time spent fetching water</b>				
<20 minutes (ref)	1.00	—	1.00	—
20–60 minutes	2.12 (1.29–3.49)	0.003	1.87 (1.07–3.29)	0.028
>60 minutes	3.87 (2.06–7.26)	<0.001	3.25 (1.61–6.54)	<0.001
<b>Water usage per day</b>				
<20 litres (ref)	1.00	—	1.00	—
20–40 litres	1.98 (1.20–3.26)	0.007	1.76 (0.98–3.15)	0.058
>40 litres	2.33 (1.31–4.13)	0.004	2.11 (1.11–4.02)	0.023

Source: Primary Data (2025)

As indicated in this Table 2, Use of lake water significantly increased the odds of reporting water access challenges compared to spring water (OR=1.82; p=0.022), likely due to exposure to untreated water sources, which aligns with findings from Mugerwa et al. (2022) in Uganda.

Respondents walking more than 500 meters to access water were 2.95 times more likely to experience water access burdens (AOR=2.95; 95% CI: 1.66–5.24; p<0.001), supporting Niyonzima and Habimana (2021), who highlighted how distance strongly correlates with water insecurity in Western Rwanda.

Those who spent over 60 minutes fetching water had 3.25 times higher odds of reporting dissatisfaction or strain in water supply, emphasizing the burden on productivity and health.

Households using more than 40 litres/day showed significantly higher odds (AOR=2.11; p=0.023), reflecting large family needs or inefficient usage, suggesting the need for education on water conservation and hygiene best practices.

**Table 3: Bivariate and Multivariate Analysis of Maintenance Practices and Satisfaction with Water Supply Services**

Variable	Bivariate Analysis		Multivariate Analysis	
	OR (95% CI)	p-value	OR (95% CI)	p-value
<b>Responsible for Maintenance<sup>1</sup></b>				
Local government	1.00 (Ref)	—	1.00 (Ref)	—
Private companies	0.78 (0.46–1.31)	0.35	0.82 (0.48–1.40)	0.46
Households/individuals	1.42 (0.88–2.28)	0.15	1.39 (0.84–2.29)	0.20
I don't know	0.52 (0.30–0.92)	0.025*	0.58 (0.32–1.04)	0.067
<b>Frequency of Maintenance<sup>2</sup></b>				
Monthly	1.00 (Ref)	—	1.00 (Ref)	—
Quarterly	0.83 (0.51–1.37)	0.47	0.89 (0.53–1.50)	0.67
Annually	0.61 (0.36–1.05)	0.075	0.65 (0.37–1.15)	0.14
None	0.22 (0.12–0.42)	<0.001**	0.30 (0.15–0.58)	<0.001**
<b>Time to Resolve Water Issues<sup>3</sup></b>				
Less than a week	1.00 (Ref)	—	1.00 (Ref)	—
1–2 weeks	0.94 (0.55–1.62)	0.83	0.89 (0.50–1.58)	0.69
More than a month	0.48 (0.27–0.85)	0.011*	0.56 (0.31–1.01)	0.053
Never resolved	0.20 (0.11–0.39)	<0.001**	0.27 (0.13–0.56)	<0.001**
No reported	1.11 (0.61–2.00)	0.74	1.02 (0.54–1.93)	0.95

Findings from the Table 3, Respondents who did not know who maintained the water infrastructure were less likely to be satisfied with services in bivariate analysis (OR=0.52;  $p=0.025$ ), though this lost significance in multivariate analysis ( $p=0.067$ ).

Lack of maintenance ("None" option) was strongly associated with dissatisfaction, both in bivariate (OR=0.22;  $p<0.001$ ) and multivariate analysis (OR=0.30;  $p<0.001$ ), confirming maintenance frequency as a strong predictor of satisfaction.

Delayed issue resolution (e.g., "Never resolved") had a strong negative association with satisfaction (OR=0.20;  $p<0.001$ ), also significant in multivariate analysis (OR=0.27;  $p<0.001$ ).

## 2.2 Sanitation Interventions Associated with Water Supply Chain alongside Kivu Lake in Nyamasheke District

Secondly, the research sought to identify the sanitation interventions linked to the water supply chain in the study area. This included examining hygiene infrastructure, practices around water handling, and measures taken to prevent contamination from source to household level.

**Table 4: Analysis of the Information about Sanitation Interventions Associated with the Water Supply Chain**

Variable	OR (95% CI)	p-value	OR (95% CI)	p-value
	Bivariate		Multivariate	
Toilet facility: Pit latrine	1.00 (ref)	<0.001	1.00 (ref)	<0.001
Toilet facility: Flush toilet	1.48 (1.10–2.01)	0.012	1.32 (1.02–1.88)	0.041
Toilet facility: VIP latrine	1.35 (0.97–1.89)	0.081	1.18 (0.83–1.69)	0.208
Toilet facility: Other	1.22 (0.85–1.76)	0.183	1.07 (0.74–1.55)	0.398
Toilet shared: Yes	1.56 (1.10–2.22)	0.013	1.41 (1.02–1.97)	0.039
Toilet shared: No	1.00 (ref)	–	1.00 (ref)	–
Handwashing: Tippy tap	1.25 (0.89–1.74)	0.198	1.12 (0.80–1.57)	0.472
Handwashing: Sink with running water	1.63 (1.12–2.37)	0.008	1.45 (1.04–2.21)	0.026
Handwashing: Bucket	1.32 (0.98–1.78)	0.067	1.24 (0.89–1.72)	0.176
Handwashing: No available	1.70 (1.19–2.42)	0.004	1.55 (1.08–2.21)	0.017
Waste disposal: Proper drainage	1.00 (ref)	–	1.00 (ref)	–
Waste disposal: Open drainage	1.85 (1.31–2.63)	<0.001	1.67 (1.22–2.45)	0.002
Main water source: Lake	2.12 (1.49–3.01)	<0.001	1.88 (1.33–2.77)	<0.001
Main water source: Borehole	1.50 (1.08–2.10)	0.015	1.39 (1.01–1.93)	0.043
Main water source: Piped	1.00 (ref)	–	1.00 (ref)	–
Main water source: Rainwater	1.28 (0.93–1.76)	0.103	1.19 (0.86–1.65)	0.227
Water safe: Yes	1.00 (ref)	–	1.00 (ref)	–
Water safe: No	1.92 (1.35–2.72)	<0.001	1.71 (1.21–2.48)	<0.001
Know water danger: Yes	1.00 (ref)	–	1.00 (ref)	–
Know water danger: No	1.70 (1.11–2.60)	0.017	1.53 (1.02–2.42)	0.039
Know benefits: Prevents diseases	1.00 (ref)	–	1.00 (ref)	–
Know benefits: Other	1.43 (1.02–2.02)	0.041	1.31 (0.97–1.83)	0.074
Know preventive: Boiled water	1.00 (ref)	–	1.00 (ref)	–
Know preventive: Hygiene	1.77 (1.25–2.52)	<0.001	1.63 (1.19–2.30)	0.003
Perception: Contamination at source	1.00 (ref)	–	1.00 (ref)	–
Perception: Contamination during storage	1.54 (1.13–2.10)	0.008	1.47 (1.09–2.04)	0.014
Storage container: Plastic	1.00 (ref)	–	1.00 (ref)	–
Storage container: Stainless steel	1.88 (1.21–2.91)	0.004	1.70 (1.15–2.53)	0.006
Storage place: Cool dark place	1.00 (ref)	–	1.00 (ref)	–
Storage place: Anywhere	1.67 (1.14–2.43)	0.022	1.53 (1.07–2.19)	0.018
Water treatment: Prevent disease	1.00 (ref)	–	1.00 (ref)	–
Water treatment: Improve taste	1.59 (1.11–2.27)	0.031	1.48 (1.04–2.09)	0.029
Treatment method: Boiling	1.00 (ref)	–	1.00 (ref)	–
Treatment method: Chlorination	1.46 (1.04–2.06)	0.027	1.35 (0.96–1.90)	0.081
Signs of contamination: Bad smell	1.00 (ref)	–	1.00 (ref)	–
Signs of contamination: Change in color	1.69 (1.18–2.43)	0.008	1.58 (1.11–2.25)	0.014

The findings presented in Table 4 provided compelling evidence on sanitation interventions associated with the water supply chain in Kagano Sector, Nyamasheke District. The analysis revealed that households with flush toilets were 1.48 times more likely to access safe water compared to those with pit latrines (OR=1.48; 95% CI: 1.10–2.01;  $p=0.012$ ; Mean=2.61; SD=0.74), and this remained significant in the multivariate model (OR=1.32;  $p=0.041$ ). Although VIP latrines (OR=1.35;  $p=0.081$ ) and other toilets (OR=1.22;  $p=0.183$ ) showed increased odds, these were not statistically significant.

Furthermore, households sharing toilets had a higher likelihood of unsafe sanitation, as shown by OR=1.56;  $p=0.013$  in the bivariate analysis and OR=1.41;  $p=0.039$  in the multivariate analysis. Regarding hygiene infrastructure, those with a sink and running water had significantly improved water outcomes (OR=1.63;  $p=0.008$ ; Mean=2.83; SD=0.61), while those without any handwashing facility were also at increased risk (OR=1.70;  $p=0.004$ ). Improper waste disposal through open drainage systems increased the odds of unsafe water conditions (OR=1.85;  $p<0.001$ ), reinforcing WHO and Rwanda's Ministry of Health guidelines that promote proper drainage. Respondents using lake water were 2.12 times more likely to report waterborne contamination (95% CI: 1.49–3.01;  $p<0.001$ ), and even those relying on boreholes showed significant odds (OR=1.50;  $p=0.015$ ), compared to piped water. Moreover, perception indicators revealed that 1.71 times more people who perceived their water unsafe (95% CI: 1.21–2.48;  $p<0.001$ ) were likely to suffer contamination, while awareness of hygiene as a preventive measure significantly predicted safety (OR=1.63;  $p=0.003$ ; Mean=3.01; SD=0.58). The findings support conclusions by Nyandwi & Nkurunziza (2023) in Rwanda and Oketch (2022) in Uganda, both highlighting the strong correlation between sanitation infrastructure and health outcomes. One woman from Rugabano emphasized, “Our lives have changed since we started using covered storage and boiling water—my children no longer get diarrhea every week.” This reinforces the importance of local sanitation behavior as a transformative factor in public health.

**Table 5: Bivariate and Multivariate Logistic Regression on the Information about Water Treatment Interventions at Household Level**

Variable	Bivariate Analysis OR (95% CI)	p-value	Multivariate Analysis OR (95% CI)	p-value
Used water container minimizes contamination (Yes)	2.84 (1.76–4.57)	0.000	2.21 (1.23–3.95)	0.007
Water collection container is clean (Yes)	3.12 (1.95–5.00)	0.000	2.49 (1.40–4.43)	0.002
Method: Boiling	2.56 (1.55–4.23)	0.000	2.08 (1.18–3.65)	0.011
Method: Chlorination	1.77 (1.03–3.04)	0.038	1.42 (0.78–2.61)	0.252
Method: Filtration	1.90 (1.00–3.60)	0.049	1.66 (0.84–3.30)	0.145
Does not treat water (Ref)	1.00 (Ref)	—	1.00 (Ref)	—
Role: To prevent disease	3.80 (2.10–6.85)	0.000	3.02 (1.55–5.88)	0.001
Role: To improve taste	1.46 (0.74–2.88)	0.271	1.31 (0.61–2.79)	0.482
Role: Don't know (Ref)	1.00 (Ref)	—	1.00 (Ref)	—
Storage container: Jerrican	1.90 (1.12–3.23)	0.017	1.58 (0.86–2.90)	0.142
Storage container: Bucket	1.22 (0.65–2.27)	0.535	1.09 (0.52–2.26)	0.821
Storage container: Pot	0.86 (0.40–1.84)	0.690	0.74 (0.30–1.82)	0.507
Storage container: Others	0.92 (0.44–1.92)	0.830	0.80 (0.34–1.86)	0.609
Gallon (Ref)	1.00 (Ref)	—	1.00 (Ref)	—
Cleans container before storing (Yes)	3.24 (1.89–5.56)	0.000	2.68 (1.42–5.06)	0.002
Materials used: Soap	2.37 (1.45–3.88)	0.001	2.10 (1.16–3.80)	0.014
Materials used: Water only (Ref)	1.00 (Ref)	—	1.00 (Ref)	—

**Source:** Primary Data (2025)

The findings from Table 5 presented strong statistical evidence regarding household-level water treatment interventions in Kagano Sector, Nyamasheke District. As shown, households that used water containers designed to minimize contamination had significantly higher odds of safe water access, with a bivariate odds ratio (OR) of 2.84 (95% CI: 1.76–4.57,  $p=0.000$ ) and multivariate OR of 2.21 (95% CI: 1.23–3.95,  $p=0.007$ ). Of the 337 respondents, 256 (75.96%) reported using such containers, with a mean score of 4.21 and a standard deviation (SD) of 0.93, indicating strong agreement.

Furthermore, 278 respondents (82.49%) reported cleaning their water collection containers, which had a bivariate OR of 3.12 (95% CI: 1.95–5.00,  $p=0.000$ ) and multivariate OR of 2.49 (95% CI: 1.40–4.43,  $p=0.002$ ), with a mean of 4.45 and SD = 0.76. Boiling as a water treatment method, reported by 164 households (48.66%), was significantly associated with

safe water (OR = 2.08, p = 0.011), while chlorination (used by 102; 30.27%) and filtration (used by 91; 27.00%) were not statistically significant in multivariate analysis. A notable 62.01% of households (209) reported treating water to prevent disease (OR = 3.02, p = 0.001, mean = 4.38, SD = 0.89), highlighting awareness of waterborne illnesses. In contrast, treating water to improve taste (used by 15.13%) had no significant effect (p = 0.482).

Regarding storage, jerricans were used by 183 respondents (54.30%), showing moderate association in bivariate (OR = 1.90, p = 0.017) but not in multivariate analysis. Cleaning storage containers before use was significant, with OR = 2.68 (95% CI: 1.42–5.06, p = 0.002) among 241 households (71.51%, mean = 4.33, SD = 0.81). Finally, use of soap to clean containers was reported by 218 respondents (64.69%), yielding significant results (OR = 2.10, p = 0.014), affirming its effectiveness. These findings align with Mugisha and Niyitegeka (2021) who found that household practices in Western Rwanda significantly influence microbial contamination levels, and with Alemu and Woldemichael (2022) who confirmed that behavioral interventions can reduce diarrheal incidence in East African rural settings. Supporting this, a respondent from Ninzi village stated, “We started boiling and covering our water after training from the local health worker, and truly, my children rarely get sick now.” These results underscore the critical role of awareness, infrastructure, and behavior in achieving sustainable water safety, reflecting Rwanda’s national priorities under the NST1 and aligning with SDG 6 on clean water and sanitation.

### 2.3 Factors Associated with Water Supply Chain Management alongside Kivu Lake in Nyamasheke District

Lastly, the study aimed to investigate both the key factors influencing effective water supply chain management and the household-level water treatment practices in Nyamasheke District. This helped to understand how local households ensure water safety and the role of environmental, behavioral, and infrastructural factors in water management.

**Table 6: Bivariate and Multivariate Analysis of Factors Associated with Water Supply Chain Management**

Variable	Bivariate OR (95% CI)	p-value	Multivariate OR (95% CI)	p-value
Main water source: Piped water (ref = Lake)	2.45 (1.65–3.63)	0.000	2.18 (1.34–3.56)	0.002
Drinking water from communal source (Yes vs No)	1.88 (1.22–2.90)	0.004	1.72 (1.08–2.76)	0.023
Daily water use: <20L (ref = >40L)	1.56 (1.01–2.40)	0.045	1.34 (0.85–2.11)	0.210
Daily water use: 20–40L (ref = >40L)	1.74 (1.14–2.66)	0.011	1.51 (0.96–2.39)	0.071
Pay for drinking water (Yes vs No)	2.01 (1.32–3.07)	0.001	1.87 (1.16–3.00)	0.009
Cost per 20L: <10 Rwf (ref = >50 Rwf)	1.29 (0.77–2.17)	0.331	1.12 (0.63–2.02)	0.702
Cost per 20L: 10–50 Rwf (ref = >50 Rwf)	1.85 (1.10–3.11)	0.021	1.60 (0.91–2.79)	0.103
Willingness to pay for water (Yes vs No)	2.70 (1.80–4.04)	0.000	2.40 (1.52–3.78)	0.000
Reason: Maintenance (ref = No reason)	2.12 (1.40–3.21)	0.001	1.94 (1.21–3.12)	0.005
Reason: Salary for water point attendants (ref = No reason)	1.67 (1.00–2.79)	0.048	1.41 (0.80–2.47)	0.216
Reason: Don’t know (ref = No reason)	1.23 (0.71–2.14)	0.454	1.11 (0.61–2.03)	0.729
Maintenance parts available: Yes (ref = No)	1.94 (1.23–3.05)	0.004	1.78 (1.05–3.02)	0.030
Maintenance parts available: Rare (ref = No)	1.36 (0.81–2.27)	0.248	1.22 (0.68–2.18)	0.493
Responsible for maintenance: Government (ref = Other)	2.05 (1.34–3.12)	0.001	1.92 (1.18–3.13)	0.009
Responsible for maintenance: NGOs (ref = Other)	1.88 (1.10–3.21)	0.020	1.69 (0.93–3.07)	0.082
Responsible for maintenance: Community volunteers (ref = Other)	1.55 (0.93–2.60)	0.091	1.38 (0.77–2.47)	0.277

**Source:** Primary Data (2025)

As indicated by Table 6, the bivariate and multivariate analysis of factors associated with water supply chain management in Kagano Sector revealed several statistically significant and positively associated predictors of improved water access and safety, based on responses from 337 participants. The investigation into the main water source showed that households relying on piped water had significantly higher odds of safe water access compared to those using the lake, with a bivariate OR of 2.45 (95% CI: 1.65–3.63, p=0.000) and a multivariate OR of 2.18 (95% CI: 1.34–3.56, p=0.002), with a mean score of 3.14 and SD = 0.91. The findings from Table 6 further revealed that drinking water from communal sources was associated with better water outcomes (bivariate OR = 1.88, p=0.004; multivariate OR = 1.72, p=0.023; Mean = 2.87, SD

= 0.77). Households that used less than 20L of water daily had higher odds of water safety (bivariate OR = 1.56,  $p=0.045$ ; Mean = 2.41, SD = 0.63), although this was not significant in the multivariate model (OR = 1.34,  $p=0.210$ ). Likewise, those using 20–40L also showed borderline significance (OR = 1.51,  $p=0.071$ ). Households paying for water had significantly better water outcomes (bivariate OR = 2.01,  $p=0.001$ ; multivariate OR = 1.87,  $p=0.009$ ; Mean = 3.23, SD = 0.85), and those willing to pay were most associated with water safety (OR = 2.70,  $p=0.000$ ; adjusted OR = 2.40,  $p=0.000$ ; Mean = 3.67, SD = 0.89), supporting recent findings by Mbabazi and Wambugu (2023) that willingness to pay is a proxy for water value awareness.

Reasons for payment such as maintenance (OR = 1.94,  $p=0.005$ ) also reflected positive attitudes, though reasons like “don’t know” had no significant impact (OR = 1.11,  $p=0.729$ ). Availability of maintenance parts (OR = 1.78,  $p=0.030$ ; Mean = 2.98, SD = 0.72) and responsibility by government (OR = 1.92,  $p=0.009$ ) were significant predictors, reinforcing Achieng and Nkurunziza (2022) who emphasized that local government leadership enhances sustainability of rural water points. One female respondent from Gasayo Village stated, “When we started contributing for pipe repairs and paying water attendants, we no longer walked to the lake daily, and my children now drink cleaner water.” These findings align with Rwanda’s National Water Policy that promotes community-managed water systems, highlighting that payment, maintenance, and responsible governance are vital for reliable supply chains in rural Africa.

## 2.4 Water Treatment Intervention at Household Level in Nyamasheke District

The fourth aim of the study was to identify the water treatment interventions implemented at the household level in Nyamasheke District, Rwanda. This involved examining the methods used by households to purify water for safe consumption, such as boiling, filtration, or the use of chemical disinfectants, and evaluating their effectiveness and consistency in practice.

**Table 7: Bivariate and Multivariate Logistic Regression Analysis on Safe Water Access**

Variable	Bivariate Analysis		Multivariate Analysis	
	OR (95% CI)	p-value	OR (95% CI)	p-value
Water Source – Colorless	2.46 (1.53–3.94)	0.001**	2.11 (1.28–3.48)	0.004**
Fenced Water Source Area	1.89 (1.20–2.98)	0.006**	1.67 (1.03–2.72)	0.036*
Proper Drainage at Water Source	2.73 (1.70–4.39)	0.000**	2.39 (1.40–4.06)	0.002**
Clean Water Transportation Container	2.94 (1.85–4.67)	0.000**	2.51 (1.50–4.22)	0.001**
Covered Container During Transport	2.42 (1.52–3.87)	0.001**	2.00 (1.23–3.27)	0.006**
Safe Water Transport Route	1.78 (1.11–2.85)	0.017*	1.45 (0.88–2.39)	0.145 (ns)
Food-Grade Water Storage Material	3.12 (1.90–5.11)	0.000**	2.76 (1.61–4.71)	0.000**
Storage Container Can Break Easily (reverse coded)	0.51 (0.32–0.82)	0.006**	0.66 (0.40–1.09)	0.103 (ns)
Storage Container Placed in Clean, Cool, Dark Area	2.64 (1.64–4.24)	0.000**	2.38 (1.42–3.98)	0.001**

Results from the Table 7, The logistic regression results provided both at the bivariate and multivariate levels revealed key determinants of safe water access among the surveyed households in Kagano Sector. At the bivariate level, almost all independent variables showed significant association with safe water access, and most retained significance after multivariate adjustment. As shown in the analysis, water that appeared colorless had significantly higher odds of being considered safe (OR=2.11, 95% CI: 1.28–3.48,  $p=0.004$ ), confirming that water clarity remains a crucial visible indicator of safety in rural communities. Similarly, the presence of fencing around water sources (OR=1.67,  $p=0.036$ ) and adequate drainage (OR=2.39,  $p=0.002$ ) were significantly associated with improved water safety, which aligns with Wambui et al. (2022) who found that infrastructure around water points significantly enhances rural sanitation outcomes in Kenya.

Regarding water transport practices, the use of clean containers (OR=2.51,  $p=0.001$ ) and covering them during transit (OR=2.00,  $p=0.006$ ) were strong predictors of safe water usage, consistent with Niyonzima and Habimana (2021) in Rwanda, who emphasized household hygiene behavior as a critical element in preventing post-collection water contamination. Although having a safe transport route was significant in bivariate analysis, it lost significance in the multivariate model, suggesting that household-level practices may play a stronger role than external environmental factors.

In terms of storage, using food-grade materials (OR=2.76,  $p=0.000$ ) and placing containers in clean, cool, dark areas (OR=2.38,  $p=0.001$ ) were strong predictors of water safety, whereas fragile containers (OR=0.66,  $p=0.103$ ) were not

significantly linked after adjustment. These results support Rwanda's National Water and Sanitation Policy, which promotes the use of proper materials and storage conditions to reduce contamination risk. One female respondent from Gikuyu village expressed her view saying, "Before, we didn't know how dirty water gets after fetching. Now we keep it covered and cool, and my children have had fewer stomach problems." Her experience reflects the positive changes possible through improved community practices and informed behavioral change.

#### IV. DISCUSSION OF FINDINGS

Effective water, sanitation, and hygiene (WASH) management in rural areas is shaped by multiple social, economic, and governance factors. As noted by Musonda and Phiri (2021), lower literacy levels in rural Zambia have been shown to constrain community uptake of water safety planning. This suggests that education and awareness are crucial in promoting safe water practices in similar contexts. Likewise, Ndikumana and Bizimana (2022) emphasized that distance and time significantly influence access to improved water sources in rural Rwanda, underlining the importance of infrastructure development and equitable distribution of water points. Governance and accountability play an equally critical role in sustaining rural water services. Achieng and Nkurunziza (2022) demonstrated that user satisfaction with water systems in Uganda depended on clear accountability structures and responsiveness to maintenance issues. Muriuki and Kamau (2021) further argued that well-defined responsibilities reduce conflict and strengthen confidence in service delivery. These insights point to the need for transparent maintenance frameworks and active community participation.

Sanitation and hygiene practices remain central to reducing waterborne disease risks. Oketch (2022) highlighted the effectiveness of behavior change strategies in improving sanitation across East Africa, while Nyandwi and Nkurunziza (2023) reported that improved sanitation practices directly lower incidences of waterborne illnesses. Similarly, Mugisha and Niyitegeka (2021) found that communities willing to financially contribute to water maintenance are more likely to protect water sources, a point also supported by Abebe and Tadesse (2022), who linked community contributions to improved accountability in Ethiopia.

Finally, household-level practices—such as proper water storage, source protection, and drainage management—are central to ensuring water safety. Rwanda's National Water and Sanitation Policy (2021) and Ndayambaje and Uwitonze (2021) both stress that these measures significantly reduce childhood diarrheal illnesses in rural communities. Collectively, the literature underscores that improving rural WASH outcomes requires not only infrastructure but also strong governance, sustained community engagement, and the promotion of safe household practices.

#### V. CONCLUSION

The study concluded that effective water supply chain management and associated sanitation interventions in Kagano Sector are critically influenced by infrastructural, behavioral, and governance-related variables. Among the variables investigated, the main water source emerged as the most significant determinant, with households relying on piped water demonstrating the highest likelihood of accessing safe and adequate water. This suggests that infrastructure development, especially expansion of piped water systems, is a priority area for government agencies and implementing partners such as WASAC, MININFRA, and local government authorities. Closely related to this was the willingness to pay for water, which revealed a strong correlation with improved water outcomes ( $r = 612^{**}$ ,  $p < .01$ ), confirming that community members value reliable water services when delivery systems are functional and well-managed. The role of sanitation infrastructure was also essential, with households possessing flush toilets or private facilities experiencing better water safety, indicating a need for integrated water and sanitation interventions.

Furthermore, water treatment behaviors, particularly cleaning containers and boiling water, were shown to significantly enhance water safety, thus underlining the importance of continuous health education campaigns and community engagement by health centers and outreach programs like Community Health Clubs (CHCs). Findings also highlighted that storage and transportation practices, including using food-grade containers and covering water during transport, are critical control points in preventing contamination. Moreover, governance and maintenance responsibilities emerged as key, with satisfaction levels tied to clarity over who manages and maintains water infrastructure. The lack of maintenance or unresolved system breakdowns contributed to dissatisfaction and diminished access. These conclusions provide new insights on the intersection of household behavior, infrastructure design, and institutional accountability in improving water and sanitation outcomes in rural Rwanda. The study informs the design of targeted programs by institutions such as Rwanda's Ministry of Health, WASAC, and district-level WASH units, and offers practical, evidence-based approaches for policymakers and NGOs to enhance sustainability, public health, and user satisfaction within rural water supply chains.

## VI. ETHICAL CONSIDERATION

Before data collection, all ethical procedures established by Mount Kigali University (MKU) were strictly followed. This includes obtaining ethical clearance from MKU, securing approval from the Institutional Review Board (IRB), and obtaining authorization from the administration of Nyamasheke District and Kagano Sector.

All participants received a clear explanation of the study's objectives, procedures, potential benefits, and any associated risks. Their participation was entirely voluntary, and they will have the right to withdraw at any time without consequences. Written informed consent was obtained before participation to ensure their full understanding and agreement. The data collected were kept strictly confidential. No personally identifiable information was shared, and responses only used for research purposes. Anonymity was maintained throughout the study to protect participants' privacy.

Collected data were securely stored to prevent unauthorized access. Digital records were password-protected, and any physical documents were kept in a locked cabinet. Data were retained only for the period necessary for analysis and reporting, after which it was securely disposed of following ethical guidelines.

## REFERENCES

- [1] Ali, S. I., Ali, S. S., & Fesselet, J.-F. (2015). Effectiveness of emergency water treatment practices in refugee camps in South Sudan. *Bulletin of the World Health Organization*, *93*, 550–558.
- [2] Aliabadi, V., Gholamrezai, S., & Ataei, P. (2020). Rural people's intention to adopt sustainable water management by rainwater harvesting practices: Application of TPB and HBM models. *Water Supply*, *20*, 1847–1861. <https://doi.org/10.2166/WS.2020.094>
- [3] Bartram, J., & Cairncross, S. (2010). Hygiene, sanitation, and water: Forgotten foundations of health. *PLoS Med*, *7*(11). <http://dx.doi.org/10.1371/journal.pmed.1000367>
- [4] Baumann, E. (2019). May-day! May-day! Our handpumps are not working! Rural Water Supply Network: Perspectives 1. Available at: <http://www.rural-water-supply.net/>
- [5] Boazar, M., Abdeshahi, A., & Yazdanpanah, M. (2020). Changing rice cropping patterns among farmers as a preventive policy to protect water resources. *Journal of Environmental Planning and Management*, *63*, 2484–2500. <https://doi.org/10.1080/09640568.2020.1729705>
- [6] Bosch, C., Hommann, K., Rubio, G. M., Sadoff, C., & Travers, L. (2021). Water, sanitation and poverty. [www.intussen.info/OldSite/Documenten/Noord/Internationaal/WB/](http://www.intussen.info/OldSite/Documenten/Noord/Internationaal/WB/) [Accessed 21 December 2012].
- [7] Brown, J., & Clasen, T. (2012). High adherence is necessary to realize health gains from water quality interventions. *PLoS One*, *7*, e36735. doi: 10.1371/journal.pone.0036735
- [8] Burden of Disease Study 2015. (2017). *Lancet Infectious Diseases*, *17*, 909–948. [https://doi.org/10.1016/S1473-3099\(17\)30276-1](https://doi.org/10.1016/S1473-3099(17)30276-1)
- [9] Caruso, B. A., Conrad, A., Patrick, M., et al. (2022). Water, sanitation, and women's empowerment: A systematic review and qualitative metasynthesis. *PLoS Water*, *1*, e0000026.
- [10] Charcosset, C. (2019). A review of membrane processes and renewable energies for desalination. *Desalination*, *245*, 214–231.
- [11] Chawla, I., Karthikeyan, L., & Mishra, A. K. (2020). A review of remote sensing applications for water security: Quantity, quality, and extremes.
- [12] Clasen, T., et al. (2015). Interventions to improve water quality for preventing diarrhoea. *Cochrane Database of Systematic Reviews*, *CD004794*. doi: 10.1002/14651858.CD004794.pub3
- [13] Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications.
- [14] Devitt, C., O'Neill, E., & Waldron, R. (2016). Drivers and barriers among householders to managing domestic wastewater treatment systems in the Republic of Ireland; implications for risk prevention behaviour. *Journal of Hydrology*, *535*, 534–546. <https://doi.org/10.1016/j.jhydrol.2016.02.015>

- [15] Ditsch, A., Lindenmann, S., Laibinis, P. E., Wang, D. I. C., & Hatton, T. A. (2019). High-gradient magnetic separation of magnetic nanoclusters. *Industrial & Engineering Chemistry Research*, 44(17), 6824–6836.
- [16] Elimelech, M., & Phillip, W. A. (2011). The future of seawater desalination: Energy, technology, and the environment. *Science*, 333(6043), 712-717.
- [17] Environmental Protection Agency, US. (2012). Disinfection by products: A reference resource.
- [18] Environmental Protection Agency (EPA). (2020). *Water infrastructure maintenance best practices*. U.S. Environmental Protection Agency. <https://www.epa.gov>
- [19] Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford, J. M. Jr. (2019). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. *Lancet Infectious Diseases*, 5(1), 42–52.
- [20] Fifth Rwanda Population and Housing Census. (2022). (NISR).
- [21] GBD 2019 Demographics Collaborators. (2020). Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950–2019: A comprehensive demographic analysis for the Global Burden of Disease Study 2019. *The Lancet*, 396(10258), 1160-1203.
- [22] Ginn, O., Rocha-Melogno, L., Bivins, A., et al. (2021). Detection and quantification of enteric pathogens in aerosols near open wastewater canals in cities with poor sanitation. *Environmental Science & Technology*.
- [23] Gleick, P. H., Wolff, G., Chalecki, E. L., & Reyes, R. (2019). The new economy of water: The risks and benefits of globalization and privatization of fresh water. *Pacific Institute*.
- [24] Hakizimana, E. (2022). The prevalence and factors associated with intestinal parasite infections among children aged 12–59 months in Rwanda: Case study: Nyamasheke District.
- [25] Hijnen, W. A. M., Beerendonk, E. F., & Medema, G. J. (2018). Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review. *Water Research*, 40, 3–22.
- [26] Hoffmann, C., & Franzreb, M. (2024). A novel repulsive-mode high gradient magnetic separator—I. Design and experimental results. *IEEE Transactions on Magnetics*, 40(2), 456–461. <https://doi.org/10.2478/v10216-011-0015-x>
- [27] IPCC (Intergovernmental Panel on Climate Change). (2019). Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. <https://www.ipcc.ch/report/srcccl/>
- [28] IPCC (Intergovernmental Panel on Climate Change). (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- [29] Jeong, J., & Ham, S. (2018). Application of the health belief model to customers' use of menu labels in restaurants. *Appetite*, 123, 208–215. <https://doi.org/10.1016/j.appet.2017.12.012>
- [30] Kerwick, M., Reddy, S., Holt, D., & Chamberlain, A. (2019). A methodology for the evaluation of disinfection technologies. *Journal of Water and Health*, 3(4), 393–404.
- [31] Khan, M. (2010). Using the health belief model to understand pesticide use decisions. *Pakistan Development Review*. <https://doi.org/10.30541/v49i4Ipp.941-956>
- [32] Klemeš, J. J., Varbanov, P. S., & Walmsley, T. G. (2018). Water-energy nexus: Strategic challenges for process industries. *Current Opinion in Chemical Engineering*, 22, 7-14.
- [33] Lam, K. L., Remais, J. V., & Fung, I. C. (2020). A global review of water supply chain disruptions. *Water Research*, 173, 115586.
- [34] Lawrence, K., & Tong, D. (2019). Feasibility of using biologically activated carbon for treatment of gaseous H<sub>2</sub>S. *Journal of the Institute of Engineers*, 45(4), 15–23.

- [35] Mahama, A. M., Anaman, K. A., & Osei-Akoto, I. (2014). Factors influencing householders' access to improved water in low-income urban areas of Accra, Ghana.
- [36] Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, 391, 2198.
- [37] Moropeng, R. C., & Momba, M. N. B. (2020). Assessing the Sustainability and Acceptance Rate of Cost-Effective Household Water Treatment Systems in Rural Communities of Makwane Village, South Africa. *Crystals*, 10(10), 872. <https://doi.org/10.3390/cryst10100872>
- [38] Mosler, H.-J. (2012). A systematic approach to behavior changes interventions for the water and sanitation sector in developing countries: A conceptual model, a review, and a guideline. *International Journal of Environmental Health Research*, 22(5), 431–449.
- [39] Moreira, T. R., Dias da Costa, G. & Mitre Cotta, R. M. (2023). Water, sanitation, and hygiene vulnerability in child stunting in developing countries: A systematic review with meta-analysis. *Public Health*. 219, 117–123
- [40] 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.
- [41] Murcott, S. (2018). *Implementation, critical factors and challenges to scale-up of household drinking water treatment and safe storage systems*. Background paper on household water treatment and safe storage (HWTS). Proceedings of the Electronic Conference Hosted by USAID/Hygiene Improvement Project (HIP), 12–22 May 2018, 1–39.
- [42] Murray, C. J., et al. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, 396(10258), 1223–1249.
- [43] Dassanayake, L. & Rusanganwa, A. (2017). Knowledge, attitude and practice of hygiene and sanitation in a Burundian refugee camp: Implications for control of a Salmonella typhi outbreak. *The Pan African Medical Journal* 28, 54.
- [44] Nasiri, A. R., Shahangian, S. A., Kerachian, R., & Zobeidi, T. (2024). Exploring socio-psychological factors affecting farmers' intention to choose a low-water-demand cropping pattern for water resources conservation: Application of the health belief model.
- [45] Nshimiyimana, L., Onyambu, P. M., & Rutayisire, E., et al. (2018). Diarrhoeal diseases in children under five years exhibits space-time disparities and priority areas for control interventions in Rwanda.
- [46] Oki, T., & Kanae, S. (2018). Global hydrological cycles and world water resources. *Science*, 313(5790), 1068-1072.
- [47] Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., et al. (2014). Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: A retrospective analysis of data from 145 countries. *Tropical Medicine and International Health*, 19(8), 894–905.
- [48] Punayani, S., Narayana, P., Sing, H., & Vasudevan, P. (2018). *Journal of Scientific and Industrial Research*, 65, 116–120.
- [49] Rai, P. K. (2019). Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. *Critical Reviews in Environmental Science and Technology*, 39(8), 697–753.
- [50] Rwanda Environment Management Authority (REMA). (2011). *Atlas of Rwanda's Changing Environment: Implications for Climate Change Resilience* (Kigali, Rwanda: REMA). <https://na.unep.net/siouxfalls/publications/REMA.pdf>
- [51] 5<sup>th</sup> Rwanda Population and Housing Census (SRPHC). (2023).
- [52] Schouten, T., & Moriarty, P. (2013). Community water, community management: From system to service in rural areas. *Practical Action Publishing*.
- [53] Shahangian, S. A., Tabesh, M., Yazdanpanah, M., Zobeidi, T., & Raoof, M. A. (2022). Promoting the adoption of residential water conservation behaviors as a preventive policy to sustainable urban water management. *Journal of Environmental Management*, 313, 115005. <https://doi.org/10.1016/j.jenvman.2022.115005>
- [54] Sharma, S., & Bhattacharya, A. (2017). Drinking water contamination and treatment techniques.

- [55] Shazia, & Amar. (2023). Drinking water quality monitoring, assessment and management in Pakistan: A review," published in the journal *Heliyon* in 2023.
- [56] Smith, L., & Hanson, S. (2023). Access to water for the urban poor in Cape Town: Where equity meets cost recovery. *Journal of Urban Studies*.
- [57] Ssemugabo, C., Wafula, S. T., Ndejjo, R., Oporia, F., Osuret, J., Musoke, D., & Halage, A. A. (2019). Knowledge and practices of households on safe water chain maintenance in a slum community in Kampala City, Uganda. *Environmental Health and Preventive Medicine*, 24, 45.
- [58] Stolarska, A. Z., & Skrzypski, J. (2012). Review of mathematical models of water quality. *Ecological Chemistry and Engineering S*, 19(4), 441-450.
- [59] Tajeri Moghadam, M., Raheli, H., Zarifian, S., & Yazdanpanah, M. (2020). The power of the health belief model (HBM) to predict water demand management: A case study of farmers' water conservation in Iran. *Journal of Environmental Management*, 263, 110388. <https://doi.org/10.1016/j.jenvman.2020.110388>
- [60] Tarkang, E. E., & Zotor, F. B. (2015). Application of the health belief model (HBM) in HIV prevention: A literature review. *Central African Journal of Public Health*, 1(1), 1-8. <https://doi.org/10.11648/j.cajph.20150101.11>
- [61] UNDP (United Nations Development Programme). (2018). *Human Development Report: Beyond Scarcity; Power, Poverty and the Global Water Crisis*.
- [62] UNICEF. (2018). *Progrès pour les enfants: Un bilan de l'eau et de l'assainissement (Progress for Children: A Summary on Water and Sanitation)*. New York, NY: UNICEF.
- [63] UNICEF. (2024). *Global annual results report 2023: Goal area 4*. <https://www.unicef.org/reports/global-annual-results-report-2023-goal-area-4>
- [64] United Nations the Post. (2015). Water Thematic Consultation: Recognition of Outcomes, High Level Forum–World Water Day. 2013. [http://www.unwater.org/downloads/Final9Aug2013\\_WATER\\_THEMATIC\\_CONSULTATION\\_REPOR](http://www.unwater.org/downloads/Final9Aug2013_WATER_THEMATIC_CONSULTATION_REPOR)
- [65] Urbanovich, T., & Bevan, J. L. (2020). Promoting environmental behaviors: Applying the health belief model to diet change. *Environmental Communication*, 14(5), 657–671. <https://doi.org/10.1080/17524032.2019.1702569>
- [66] Von Gunten, U. (2023a). Ozonation of drinking water: Part I. Oxidation kinetics and product formation. *Water Research*, 37(7), 1443–1467.
- [67] Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., ... Vos, T., et al. (2020). Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, 396(10258), 1204–1222.
- [68] World Bank. (2013). *World Development Indicators / Global Development Finance Database*. Retrieved from <http://data.worldbank.org/data-catalog/>
- [69] World Bank. (2021). *The role of digital technologies in enhancing water system resilience: Applications of predictive analytics and monitoring tools*. World Bank Group. <https://www.worldbank.org/en/topic/water/publication/the-role-of-digital-technologies-in-enhancing-water-system-resilience>
- [70] World Health Organization & UN-Habitat. (2018). *Progress on safe wastewater treatment and use: Testing the tracking method and preliminary results for SDG indicator 6.3.1*. Available from: <https://apps.who.int/iris/handle/10665/275968> (accessed 28 October 2022).
- [71] World Health Organization (WHO), & UNICEF. (2017a). *Safely Managed Drinking Water - Thematic Report on Drinking*.
- [72] World Health Organization (WHO), & UNICEF. (2017b). *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. Geneva, Switzerland: World Health Organization.

- [73] World Health Organization (WHO), & UNICEF. (2019). *Methodological Note: Proposed Indicator Framework for Monitoring SDG Targets on Drinking Water, Sanitation, Hygiene and Wastewater*. Geneva, Switzerland: World Health Organization.
- [74] World Health Organization (WHO). (2019). *Safer water, better health*. Geneva, Switzerland: World Health Organization.
- [75] World Health Organization. (2019). *WHO strategy on water, sanitation and hygiene 2018–2025*. Available from: <https://apps.who.int/iris/handle/10665/311284> (accessed 28 October 2022).
- [76] World Health Organization. (2019). *Guidelines on sanitation and health*. World Health Organization. <https://www.who.int/publications/i/item/9789241514705>
- [77] World Health Organization. (2022). Water safety planning: A roadmap for managing drinking-water quality. <https://www.who.int/publications/i/item/9789241515430>
- [78] WHO/UNICEF. (2014). Joint Water Supply and Sanitation Monitoring Programme. Progress on Drinking Water and Sanitation. 2013.
- [79] WHO/UNICEF. (2021). Joint Monitoring Program for Water Supply, Sanitation and Hygiene (JMP) – Progress on Household Drinking Water, Sanitation and Hygiene (2000–2020). Available from: <https://washdata.org/>. (Accessed 22 January 2024).
- [80] Yazdanpanah, M., Moghadam, M. T., Zobeidi, T., Turetta, A. P. D., Eufemia, L., & Sieber, S. (2022). What factors contribute to conversion to organic farming? Consideration of the health belief model in relation to the uptake of organic farming by Iranian farmers. *Journal of Environmental Planning and Management*, 65(5), 907–929. <https://doi.org/10.1080/09640568.2021.1917348>
- [81] Zetu, L., Zetu, I., Dogaru, C. B., Duță, C., & Dumitrescu, A. L. (2014). Gender variations in the psychological factors as defined by the extended health belief model of oral hygiene behaviors. *Procedia - Social and Behavioral Sciences*, 127, 358–362. <https://doi.org/10.1016/j.sbspro.2014.03.271>