Water safety in the water distribution networks of small towns

The case of Bushenyi-Ishaka municipality, Uganda

Josphine Gaicugi

MSc Thesis **UWS-WSE.19-30**

27/03/2019

Updated Version, 11/05/2019

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Master of Science Thesis

by

Josphine Gaicugi

Supervisor

Prof. Maria Kennedy

Mentor

Dr. Giuliana Ferrero

Examination Committee

Prof. Maria Kennedy

Dr. Giuliana Ferrero

Dr. Sara Marks

This research is done for the partial fulfillment of requirements for the Master of Science degree at the UN-IHE Institute for Water Education, Delft, The Netherlands.

Delft

27/03/2019

Abstract

Water safety is vital for human health and development. About 780 million people globally lack access to improved water sources. Improved water sources are regarded as safely managed sources by World Health Organization (WHO) but they are prone to recontamination. Recontamination of treated water has been observed to occur in the piped water during transport and distribution up to the point of consumption. Small water supplies are more prone to faecal contamination. Problems in the water distribution network are responsible for 30% of waterborne diseases outbreaks in piped water supply systems. Unfortunately, due to the complexity of water distribution networks, it is challenging to assess water safety. The WHO issues guidelines for drinking water quality that are used by water suppliers. These guidelines advocate for the implementation of risk assessment and risk management approaches (water safety plans (WSPs), sanitary inspections) to ensure the safety of drinking water in line with these guidelines.

To accurately assess water safety in the distribution network, development and improvement of risk assessment tools is essential. Currently, as part of the development of the new guidelines for small drinking water supplies, the WHO is revising the existing sanitary inspection forms. The aim is to align them with WSPs ensuring that appropriate risk factors are considered specifically to create sanitary inspection forms that better approximate microbial risk, and also to improve the user-friendliness for water operators.

This study was aimed at carrying out a risk assessment of piped water distribution network using sanitary inspections and water quality analysis, and at the same time piloting and testing the draft sanitary inspection form for piped distribution. The objectives of this study were: a) to identify risks in the water distribution network, b) to evaluate the statistical correlation between *E. coli* concentrations and sanitary risk scores, c) to determine the predictive value of the sanitary inspection form, and d) to determine the scale at which the sanitary inspection form is more applicable.

One hundred sixty-nine samples were collected from the water distribution network of Bushenyi-Ishaka municipality in Uganda managed by the National Water and Sewerage Corporation. *E. coli* was detected in 56% of the samples collected. Based on sanitary risk scores, at the village level, 7% of the samples were at low risk, 73% intermediate risk and 20% high risk. Tap stands within 10 m proximity of signs of pollution (latrine, rubbish, and animals) were more likely to show *E. coli* presence. There was a very weak positive statistical correlation between sanitary risk scores and *E. coli* presence, however this relationship was not statistically significant. The positive predictive value of these risk factors for *E. coli* presence was 90% at village scale and 82% at a medium scale, while the negative predictive value is 3% and 38% respectively. However, the area under the curve for a ROC curve shows that the accuracy of the predictive value is 55% at village scale and 62% at medium scale. This indicates that the sanitary risk scores have poor ability to predict the presence and absence of *E. coli* concentrations.

Among the risks identified, low pressure in the network, low chlorine residual, and pipe breaks and bursts and also presence of signs of pollution in the vicinity of the tap stand were ranked as

the risk factors that pose high risk to the water distribution network. Based on the results at different scales there was a minimal difference between the productivity at each scale. Therefore, the sanitary inspections can be applied at any scale.

Acknowledgments

I would like to thank my mentor Dr. Giuliana Ferrero continuous support during my master thesis and research, for her patience, motivation, enthusiasm, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis.

I would also like to extend my gratitude to the project SMALL for funding the project in Uganda, and for the support from the team members and NWSC staff in Bushenyi.

Special mention of Francis Kateeba for the office space and the assistance offered all through my data collection in Bushenyi.

Finally, I must express profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Thank you.

Josphine Gaicugi

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Abbreviations

WSP	Water Safety Plan
WHO	World Health Organization
SDG	Sustainable Development Goal
NWSC	National Water and Sewage Corporation
WDN	Water Distribution Network
E. coli	*Escherichia coli*
SIF	Sanitary Inspection Form
NRW	Non-Revenue Water
ROC curve	Receiver Operating Characteristic curve
SPSS	Statistical Package for the Social Sciences
TTC	Thermo-tolerant Coliform
TC	Total Coliform

Chapter 1 Introduction

1.1.1 Background of the study

In sub-Saharan Africa, more than 300 million people lack access to safe drinking water. Unsafe drinking water exposes consumers to preventable health risks such as diarrhoea, typhoid fever and cholera (Guragai, et al., 2017). Every year, about 800,000 children die from diarrhoea across the world (Prüss-Ustün, et al., 2014). In the recent past, cholera outbreaks took place in Zimbabwe and Uganda. According to the World Health Organization (Eslami, et al., 2018), these outbreaks have been attributed to ingestion of contaminated drinking water and failing water supply and sanitation infrastructure. Water safety is therefore vital for human health and development.

To ensure the provision of safe water towards achieving SDG 6.1, the WHO has classified water sources according to the level of water safety. Improved water sources include piped water supply systems (connected to dwelling, yard/plot or public standpipes), tube wells/boreholes, protected dug wells, protected springs, and rainwater (Bain, et al., 2014). In parallel, the WHO is in charge of setting international guidelines that govern water safety and public health worldwide. The purpose of these guidelines is to provide guidance on harmful substances and to advise governments and water suppliers on how to prevent or minimize the contamination of source waters, reduce or remove the contamination through treatment processes, and to prevent the contamination during storage, distribution, and handling of drinking water (WHO, 2017). Unfortunately, recontamination has been observed to occur slowly and steadily after treatment, during transmission and distribution up to the point of consumption (Bain, et al., 2014).

Studies have shown that, for piped water supply systems, about a third of waterborne outbreaks are a result of problems in the water distribution network (WDN) (WHO, 2014). These diseases occur as a result of pathogen intrusion into the WDN and microbial growth. The primary driver to pathogen intrusion is the failure to maintain a minimum pressure in the WDN due to breach of integrity (physical, hydraulic or water quality) in the distribution network (Fontanazza, et al., 2015). Practically, it is difficult to tell the specific cause or pathway for pathogen intrusion in the distribution network because they are interlinked with each other. For example loss of pipe pressure due to breach of hydraulic integrity increases the impacts of loss of physical integrity. Intermittent water supply affects water quality integrity by increasing water age and promoting biofilm growth (WHO, 2014). Although most of these events may not lead to waterborne outbreaks, they can lead to periodic diseases that may go undetected but have an adverse health impact on the consumers (Besner, et al., 2011).

1.1.2 Problem statement

To manage water safety in WDNs, the WHO has developed and recommend various tools for water safety management which involve the use of comprehensive risk assessment and risk management approaches (WHO, 2014). These tools include water safety plans (WSP), quantitative microbiological risk assessment (QMRA) and sanitary inspections (WHO, 2016). These play an essential role in hazard identification, evaluation of hazardous events, evaluating the efficacy of control measures to prevent contamination, and in the general strategic planning for management purposes (WHO, 2016, WHO, 2014). WSP and QMRA have been used effectively for risk assessment in large water supply systems. However, due to the complexity of the distribution networks, there have been limited studies assessing microbial risk in the distribution network of piped water supplies (Blokker, et al., 2014, Hamouda, et al., 2018, Schijven, et al., 2016).

In Uganda, the National Water and Sewerage Corporation (NWSC) developed 20 WSPs to date, and only a few were implemented in small water supplies, one of which is Bushenyi-Ishaka water supply system in western Uganda. According to recent research carried out on WSPs in Uganda (Nakanjako, 2018), Bushenyi's WSP has not been developed to completion while those of large urban centers have been developed to completion. Incompletion of WSPs development has been generalized for small water supplies by many researchers and has been attributed to high expertise and resource required (Godfrey, et al., 2018), (Kumpel, et al., 2018), (Nakanjako, 2018).

Given the resources and expertise required to carry out a risk assessment in WDNs using WSPs and QMRA, there is need to develop and implement easy to use and cost-effective risk assessment tools that require fewer resources and skills, thus convenient for water supplies in small towns (WHO, 2016). Sanitary inspections were first recommended by WHO in 1997 and have been in use since. At local level, they assist operators, and water and health officers in identifying causes and pathways of contamination and using these findings to come up with befitting control measures(WHO, 1997). Environmental health specialists and the WHO have therefore recommended sanitary inspection as an alternative risk assessment tool to be used in identifying deficiencies and lack of integrity in the system that can lead to or influence contamination of water in the WDN (Misati, et al., 2017, WHO, 1997). Sanitary inspections have been developed and used to carry out risk assessment for tube wells, groundwater, household surveys, boreholes, hand-dug wells and for small water supplies (Barber, et al., 2018, (Barthiban, et al., 2012), (Lutterodt, et al., 2018), (Mushi, et al., 2012, Shamsuzzoha, et al., 2018, Snoad, et al., 2017).

Generally, sanitary inspections are quick to operationalize since they do not require any special equipment making them inexpensive and easier to implement compared to microbiological water quality analysis (Mushi, et al., 2012). However, some studies have shown that sanitary inspections cannot replace water quality monitoring (Misati, et al., 2017, WHO, 1997). Instead, these two activities should be used together as they complement each other; that is, sanitary inspections identify risks while water quality analyses indicate the presence of contamination and its intensity (Snoad, et al., 2017), WHO, 1997, (Misati, et al., 2017). To improve the usability and predictive value of sanitary inspection forms (SIFs) the WHO, together with the University of Surrey, is reviewing and updating existing SIFs and developing new ones (WHO, 2018). Specifically, due to the complexity of WDNs, no SIF for this part of the piped supply chain has been developed in the past. Currently, the WHO and the University of Surrey are developing a sanitary inspection form for piped distribution, which was piloted in the course of this study.

In the case of Bushenyi-Ishaka, a general risk assessment had been carried out recently for the whole water supply system using the WSP approach (Nakanjako, 2018, Twesigye, 2018). This assessment showed that the system is highly at risk of microbial contamination and thus in dire need of implementation of the proposed improvement plan. Unfortunately, due to its broadness, it is unable to connect the specific risks identified in the WDN to the specific problem areas. Based on these findings, this study was meant to carry out a risk assessment in Bushenyi-Ishaka WDN using sanitary inspections as a risk identification tool and water quality analysis to indicate the intensity of contamination.

1.2 Goal and objectives

The goal of this study was to carry out a risk assessment in the distribution network of Bushenyi-Ishaka water supply system.

The specific objectives are:

- To identify hazards and hazardous events in the water distribution network by performing sanitary inspections.
- To evaluate the statistical correlation between sanitary inspections and water quality monitoring data.
- To understand the predictive value of sanitary inspection forms for assessing the risks in the water distribution network.
- To evaluate the most suitable scale at which sanitary inspection forms should be applied.

1.3 Research questions

1. Are sanitary inspection forms adequate to support operators of small water supply systems in identifying risks in the water distribution network?
2. Is there a statistical correlation between the risks identified and the drinking water quality monitoring data?
3. Can sanitary inspections predict microbial contamination in the WDN?
4. Does the scale at which the sanitary inspection forms are applied have an impact on their outcome?

Chapter 2 Literature review

2.1 Water safety

According to the WHO, safely managed water is water that is easily accessible on premises, available when needed, and free from microbiological and priority chemical contamination (WHO, 2017). Safe drinking water can be obtained from improved water sources such as piped water supply systems (connected to dwelling, yard/plot or public standpipes), tube well/boreholes, protected dug wells, protected springs and rainwater collection (WHO, 2014).

To supply safe drinking water, water supply companies and organizations should ensure effective management and operation throughout the drinking water supply chain from the catchment and source to the consumption points. The WHO has therefore developed guidelines that incorporate a water safety framework. These guidelines aim to prevent or minimize the contamination of source waters, reduce or remove the contamination through treatment processes and, to prevent the contamination during storage, distribution, and handling of drinking water (Fewtrell, 2001). The water safety framework involves the use of a comprehensive risk assessment and risk management approaches that encompass all steps in the water supply from catchment to consumer outlet (Fewtrell, 2001, WHO, 2017).

According to (WHO, 2017):

- A hazard is a microbiological, chemical, physical or radiological agent that has the potential to cause harm.
- A hazardous event is an incident or situation that can lead to the entry of a hazard into the water supply system.
- Risk is defined as the likelihood of identified hazards to cause harm to the exposed consumers in a specified time frame, including the magnitude of that harm and the consequences.

The water safety framework is a cyclic process that involves five components that are necessary to deliver safe drinking water.

- **health-based targets** for microbial and chemical water quality,
- **system assessment** to determine whether the water supply chain from catchment to consumer can deliver safe drinking water at the point of consumption,
- **Monitoring of identified control measures** within the water supply chain that assures safety,

- **Management plans** documenting the system assessment and monitoring and which describe the actions to be taken during normal operation and incident conditions to secure water safety,
- **Public health surveillance** of water safety.

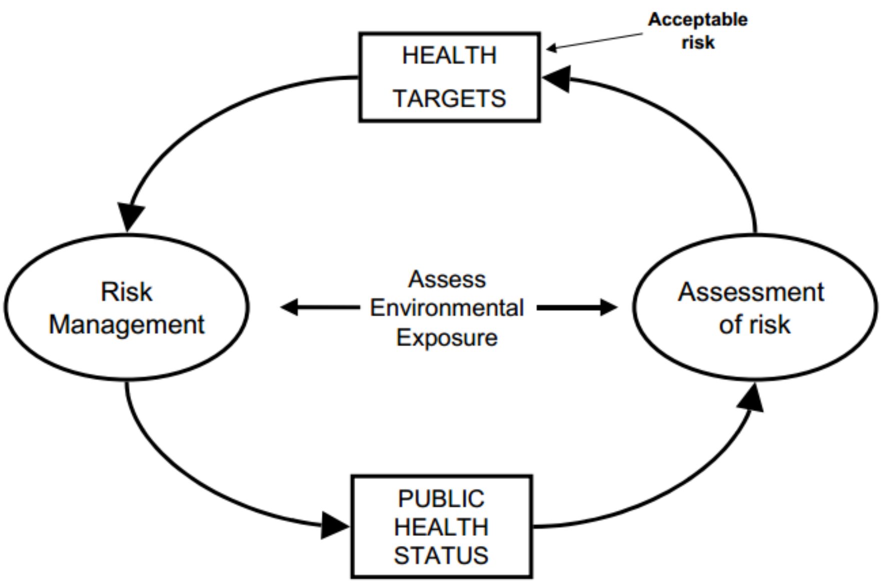

Figure 1 framework for drinking water safety (WHO, 2005)

2.2 Methodologies for risk assessment and risk management in drinking water systems

For drinking water supply systems, risk assessment is an integral part of water safety. Risk assessment is an important process carried out on water supply systems to identify hazards and evaluate the health risks associated with water supply, reassess existing control measures, to allow informed decision making among operators and the management during master planning and network rehabilitation in pursuit of ensuring delivery of safe drinking water (WHO, 2014).

The most commonly used risk assessment tools for drinking water safety are WSPs, QMRA and sanitary inspections (WHO, 2014). During risk assessment, it is crucial to ensure that contaminant source-pathway-receptor relationships are kept in mind.

2.2.1 Sanitary inspections

A sanitary inspection is an on-site inspection that evaluates all conditions, structures, and practices in the water-supply system that pose an actual or potential risk to the health and well-being of the consumer. Generally, it is an applicable tool for collecting information about the specific risks to the water supply systems (WHO, 1997). Sanitary inspections are easy to use and require the least amount of resource compared to other risk assessment tools. They are thus widely used in small water supplies for hazard identification and prioritization of risks. Sanitary inspections can be used as support for WSP implementation, as part of QMRA for risk identification and can also be used as a composite analysis method together with water quality monitoring for a reassessment of control measures and help recommend needful actions (Barthiban, et al., 2012, Misati, et al., 2017, Snoad, et al., 2017, WHO, 2016). Combination of water quality monitoring and sanitary inspection was suggested by Lloyd & Bartram (1991) as part of surveillance solutions for microbiological problems, then recommended in Volume 3 of the second edition of the WHO guidelines for drinking water quality (WHO, 1997).

According to WHO, sanitary inspections should be done periodically by the water supply agency staff and surveillance agency. The suggested minimum annual frequency of the sanitary survey is monthly by the water supply agency and yearly by the surveillance agency (WHO, 1997). Furthermore, as part of the development of the new Guidelines for Small Drinking-water Supplies, WHO is currently revising the existing SIFs (WHO, 2018). This is primarily to ensure that;

- There is greater alignment with the water safety plan (WSP) approach
- the most relevant and scientifically valid risk factors (or questions) are included
- the most appropriate technologies are covered

Throughout this process, there has been some expert consultations (2015-2018), meetings of the expert working group for development of the small systems guideline (2015 and 2017), extensive literature review (2017) and piloting in (2017-2018). During this work, many recommendations have been given towards informing the development of revised SIFs (WHO, 2018).

The following recommendations have been given so far throughout this process (WHO, 2018):

1. Greater alignment with the WSP approach is needed, in particular around the introduction of elements of risk assessment and prioritization, and documenting corrective actions;
2. best practice techniques and management advice should be provided to support the user to complete the SIFs, optimally manage the system, and guide appropriate corrective actions;
3. The inclusion of an overall "contamination risk score" (and subsequent system risk classification of low to very high) as per the existing 1997 SI forms may be misleading. It should be removed (e.g., in the case where only one risk factor may be identified, yet this risk factor is significant, such as where there is a close proximity of sanitation facilities to a water source)
4. The existing SIFs format and illustrations should be revised to improve the user-friendliness of the forms;

5. The SIFs should be developed for field-level individuals conducting drinking-water quality surveillance activities, as well as those involved in water supply system management (which may include water safety planning activities);
6. The revised SIFs should maintain the overall simplicity and easy-to-use appeal of the existing 1997 SI forms.

Many household surveys and general water supply system assessments have been carried out using sanitary inspections to identify health risks associated with drinking water. These have been primarily for groundwater such as boreholes, shallow wells, protected springs, and rainwater harvesting systems as shown in Table 2.2-1 (Barthiban, et al., 2012, Misati, et al., 2017, Snoad, et al., 2017, Tosi Robinson, et al., 2018). Vf

Among them the statistical correlation between sanitary inspections and water quality data has given mixed results. Many of these studies carried out on whether risks assessed through SIFs correlate with measured water quality have shown a weak statistical correlation(Barthiban, et al., 2012, Ercumen, et al., 2017, Folarin, et al., 2013, Luby, et al., 2008, Misati, et al., 2017, Snoad, et al., 2017, Tosi Robinson, et al., 2018). Many concluded that sanitary inspections could not replace water quality analysis, but they can be used to predict potential sources of contamination. Moreover, a study carried out on the predictive value of sanitary inspections in Tanzania, showed a positive predictive value (87% of *E. coli* presence was predicted by sanitary inspection) (Mushi, et al., 2012). Another study carried out on tube wells in Bangladesh showed that the risk factors had a predictive value of less than 50% indicating that sanitary inspections do not sufficiently characterize the microbiological quality of water (Ercumen, et al., 2017).

It is, therefore, more likely that correlation between sanitary inspection and measured water quality data is indicator specific, source-specific and context specific; more research is needed to understand the appropriate scale and context to use SIFs in place of water quality testing.

Author	Research topic	Source Type	Indicator	Findings
Misati, 2017	Can Sanitary Surveys Replace water quality testing? Evidence from Kisii, Kenya	Dug wells, springs and rainwater systems	Thermostat Coliform	There were no significant associations between TTC levels and overall sanitary survey scores or their components. Contamination by TTC was associated with source type dug wells, and springs were more contaminated than rainwater systems
Snoad, 2017	The Effectiveness of Sanitary Inspections as a Risk Assessment Tool for Thermotolerant Coliform Bacteria Contamination of Rural Drinking Water: A Review of Data from West Bengal, India	Deep hand pump, Shallow hand pump, Unprotected spring, Gravity-fed piped, Unprotected dug well	Thermotolerant Coliforms	The sanitary inspection score has poor ability to identify TTC-contaminated sources.
Ercumen, 2017	Can Sanitary Inspection Surveys Predict Risk of Microbiological Contamination of Groundwater Sources? Evidence from Shallow Tube wells in Rural Bangladesh	Tube wells	Escherichia coli	Sanitary scores were not associated with *E. coli* presence or concentration. These findings indicate that observed characteristics of a tube well, as measured by sanitary inspections in their current form, do not sufficiently characterize microbiological water quality, as measured by *E. coli* .
Mushi, 2012	Sanitary inspection of wells using risk-of-contamination scoring indicates a high predictive ability for bacterial faecal pollution in the peri-urban tropical lowlands of Dar es Salaam, Tanzania	Wells (not well defined)	Escherichia coli Total coliform	ROC scoring demonstrated a remarkable ability to predict bacterial faecal pollution levels in the investigated well water (87% of *E. coli* concentration variations were predicted by ROC scoring)
Folarin, 2013	Water Quality and Risk of Diarrhoeal Infections among Children under Five in Ibadan, Nigeria	Deep well Shallow Wells Stored water	Escherichia coli	Results of sanitary inspection show that mean risk scores among cases and controls were 5.4 ± 2.2 and 3.2 ± 1.9 ($p<0.05$) for drinking water sources and 2.4 ± 1.8 and 1.2 ± 0.7 ($p<0.05$) for household storage containers. The results show a significant association between the quality of the source and stored water and diarrhoeal disease incidence among U-5C (OR=0.076, $p<0.05$).
Yentumi, 2019	An assessment of the replicability of a standard and modified sanitary risk protocol for groundwater sources in Greater Accra	Boreholes Wells(not well defined)		Linn's concordance correlation coefficient indicated very high agreement between the two observers' risk scores ($n = 62$; $c = 0.949$, 95% confidence limits 0.917–0.968). However, risk scores from urban-specific observations were uncorrelated with those from the standard protocol ($r = 0.11$, $p = 0.41$ for observer 1; $r = 0.16$, $p = 0.22$ for observer 2).

Table 2.2-1 showing studies carried out using sanitary inspections

2.2.2 Water safety plans

WSP is a widely adopted approach to drinking water safety; it is used for both large and small water supply systems. Its practical application is essential to ensure multi-barrier protection against contamination of water from catchment to consumer (WHO, 2017, WHO, 2014).

It is a risk management tool that:

- Identifies hazards and the associated level of risks
- Risk control
- Decides on means of monitoring the control measures
- How the operator can tell if a control has been lost;
- What actions are required to restore control and
- How the effectiveness of the whole system can be verified.

Many water supply systems have adopted WSP as a water safety tool. In Uganda, the National Water and Sewerage Corporation (NWSC) developed 20 WSPs till date and only a few were done in small water supplies, one of which is for Bushenyi water supply system in western Uganda. According to recent research carried out on WSPs in Uganda by (Nakanjako, 2018) Bushenyi's WSP has not been developed to completion. This problem has been generalized for small water supplies by many researchers (Godfrey, et al., 2018, Kumpel, et al., 2018, Nakanjako, 2018).

Risk matrices are the method of risk assessment for WSPs. The likelihood of a hazardous event to occur and the severity of its hazard are combines to calculate the risk rating. The WSP team establishes severity levels beforehand to make the assessment easier. The risk matrix correlates the likelihood of an event with the severity of its consequence to obtain risk scores and therefore be able to prioritize the risks (Nakanjako, 2018, WHO, 2014). The team nonetheless finds it difficult to come to a universal stand while defining the level of severity and likelihood of hazards. It is also difficult to come up with consistent criteria for all hazards. WSPs risk matrices are thus termed as laborious and time-consuming. Evaluating the efficiency of control measures is difficult because of the time and resource required. These matrices are therefore not the best for small water supplies in developing countries as it would cost them many resources to assess or reassess risks in the distribution system (Hamouda, et al., 2018).

According to research, it is evident that small water supply utilities require greater attention and additional resources to implement all the stages of WSPs in sub-Saharan Africa. The cost-effectiveness of water safety planning should be improved by the application of risk-based water management approaches (Godfrey, et al., 2018, Peletz, et al., 2016). Initiatives to implement WSPs in low resource settings tend to focus on hardware provision (laboratories, diagnostic equipment, and data management tools) and staff training. Unfortunately, the results of these efforts are rarely measured in small water supplies due to insufficient resources (Kumpel, et al., 2018, Peletz, et al., 2018).

2.2.3 Quantitative microbial risk assessment (QMRA)

QMRA is carried out to allow quantification risk from exposure to microorganisms. It is an approach that relies on the identification of pathway of hazardous exposure to assess health risk (WHO, 2016, WHO, 2014).

QMRA involves four steps;

- **Hazard Identification**: it defines pathogenic microorganisms (e.g., protozoan, virus, and bacteria) and also investigates the effect of the microbes on human health. Since the identification of all pathogens is impractical and time-consuming, specific pathogens are selected and referenced to QMRA.
- **Exposure Assessment**: this identifies pathogen pathways into human bodies such as inhalation, ingestion, dermal absorption, the exposure period, and the amount or the level of the exposure. The main focus of this assessment is the amount of oral consumption per day; this form of assessment is biased because there is a big difference in the amount of water consumed depending on many factors.
- **Dose-Response Assessment**: this links pathogen pathways to the probability of sickness and death. Numerous studies are carried out on different hosts to observe the response to the dose and aggregated later in a QMRA database. The database assumes the response as either a beta poison or exponential model.
- **Risk Characterization**: This combines the probability of exposure and related health effects to generate a quantitative measure of risk.

Many microbiological risk assessments carried out in the distribution network are have been operationalized using QMRA models (Blokker, et al., 2014, Hamouda, et al., 2018, Schijven, et al., 2016). The effectiveness of QMRA models depends primarily on the level of sophistication applied in terms of mathematical models, level of quantification and expertise. Therefore, to implement QMRA, sufficient data to support the analysis; expertise and institutional support necessary to undertake the required assessment; and the accessibility to tools to support the implementation is required. It is thus difficult to implement QMRA on small water supplies because of lack of enough relevant data and inadequate funds to hire necessary experts (Hamouda, et al., 2018, WHO, 2016). Consequentially, QMRA cannot be used on a routine basis for risk assessment.

2.3 Microbiological water safety in the distribution network

WDNs are a critical barrier in providing water safety in piped supply systems, yet are often neglected (WHO, 2014). The research topic of water safety in the distribution network has gained popularity in the past decade. Hydraulic analysis has been used to model the transport of microbial contaminants while WSPs and QMRA have been used to evaluate the potential health risk associated with these events (Besner, et al., 2011, Blokker, et al., 2014, Hamouda, et al., 2018, Schijven, et al., 2016).

Due to the complexity of WDNs, detection of the sources and pathways for microbiological risks takes time. As presented by (Shortridge and Guikema, 2014), exposure of such risks depends on the number of pathogens entering the distribution system, their transportation, and dilution throughout the system, and the number of users who eventually consume the contaminated water. Research focused on the events that lead to microbial contamination of water in the distribution network such as pathogen intrusion, leaking pipes, presence of pathogens in the soil, low and negative pressure transients and intermittent water supply have been carried out in the past (Besner, et al., 2011, Islam, et al., 2015, Shortridge and Guikema, 2014).

However, risk assessment for contaminant intrusion in the distribution network is a difficult task because it is based on the assessment of microbiological growth, inactivation by disinfection and treatments. The distribution network is a connection of many pipes and therefore difficult to assess a small part of the network. There is thus limited studies assessing microbial risk in the distribution network (Blokker, et al., 2014, Hamouda, et al., 2018, Islam, et al., 2015, Schijven, et al., 2016).

2.3.1 Pathogen intrusion

Pathogen intrusion in the WDN can be described as the entry of harmful micro-organisms into the distribution pipes. Pathogen intrusion happens when there is a presence of pathogens in the environment surrounding the water mains, a pathway allowing pathogens into the pipe such as leakage or breakage and a driving force like low or negative pressure in the water pipes (Islam, et al., 2015). Low or negative pressures in the distribution network occur when there is a breach of integrity in the network, this can be physical, hydraulic or water quality integrity. Loss of physical integrity is mainly caused by ageing and deterioration of pipes, water transients or external pressures (Besner, et al., 2011, Islam, et al., 2015).

Distribution networks most vulnerable to pathogen intrusion are those with intermittent water supply. Intermittent supply of piped water is common practice not only in developing countries but also in developed countries. This supply has its advantages in catering for water shortage, saving supply costs and reducing background water losses but it also leads to increased risk of contaminant intrusion. These supplies are characterized by long periods of no supply, poor operation and maintenance, unimproved sanitation in the area and a combination of integrity breach problems. Pathogen intrusion occurs during the emptying period when the pipes are depressurized and the pathogens are transported during supply period. The system is subjected to a cycle and reaches a steady state of pathogen presence (Besner, et al., 2011, Fontanazza, et al., 2015, Islam, et al., 2015, WHO, 2014).

Many studies have been conducted regarding pathogen intrusion and water quality deterioration, but it is challenging to differentiate the sources of contamination. Nonetheless, failure to detect these hazardous events can have a potentially adverse health impact on the consumer (Besner, et al., 2011, Islam, et al., 2015, Rural Community Assistance Partnership, 2012, WHO, 2014).

2.3.2 Impact of pathogen intrusion on human health

Impact of pathogen intrusion on human health is dependent on: the number of pathogens entering the system, duration of contaminant intrusion and concentration of pathogens reaching the consumer taps (Besner, et al., 2011). The impact on public health is high for systems under intermittent water supply. This has led to numerous reports of waterborne outbreaks and increased risk of gastrointestinal illnesses in the recent past. Few cases of GI illnesses lead to doctor examinations; this makes it difficult to track health outcomes (Islam, et al., 2015, Shortridge and Guikema, 2014).

There have been many studies carried out on the impact of contaminant intrusion on public health. The highly reported outbreaks are *Escherichia coli, Giardia intestinalis,* sporadic cryptosporidiosis and other gastrointestinal illness that are highly indicated by diarrhoea. Endemic illnesses associated to ingestion of drinking water have been investigated through household surveys, QMRA risk assessment models, water quality testing and using WSP risk matrices (Barber, et al., 2018, Shortridge and Guikema, 2014).

2.4 Hazards and hazardous events in the distribution network

Most microorganisms found in the water supply system are harmless to the consumers. However pathogenic micro-organisms can intrude into the distribution network and survive and in some cases grow provided the right environment. Faecal contamination is a very common source of microbial contamination in drinking water. Faecal contaminants are introduced into the distribution network when pathways such as leakage, cross-connection, and open storage tanks exist in the WDN. The presence of faecal contamination is monitored through the presence of indicator bacteria in the said water supply system. The most common indicator bacteria are *Escherichia coli*, thermotolerant bacteria, and total coliform bacteria (Bain, et al., 2014, WHO, 2014).

Hazardous events can lead to direct contamination such as direct entry of faecal contamination or indirectly as nutrients for pathogen growth or lead to bio-film growth in the pipe network. Hazardous events that can occur in water distribution can be categorized based on integrity breached by the event and the water quality within the system.

- **Physical integrity:** a loss of physical integrity is when the physical barrier of the distribution system is compromised such that it does not prevent intrusion of external contaminants, thus affecting the quality of water. These include structural failures of the distribution system components (pipes, valves, and storage reservoirs), cross-connections, backflow and human activity (unsanitary activities during construction or vandalism).

- **Hydraulic integrity** is the capacity to maintain desirable water flow, water pressure, and water age in a distribution system, taking into account potable water delivery and fire flow conditions. Factors that lead to loss of hydraulic integrity include; change in flow or pressure due to operational irregularities and impact due to construction and repairs. Maintaining adequate pressure in the distribution network is the key to hydraulic integrity, change in pressure in the distribution network can easily result in backflow (from cross-connections) or contaminant intrusion through pipe leaks and other types of orifices (deflections at flexible couplings, leaking joints, and deteriorating seals).

- **Water quality integrity:** loss of water quality integrity refers to circumstances or a situation that leads to a negative change in the water quality such as biofilm growth, leaching, pH, chlorine residual, corrosion, water age, stagnation/high retention times (due to dead ends) and discolouration.

Practically, it is difficult to tell the specific cause or pathway for pathogen intrusion in the distribution network because they are interlinked with each other. Loss of hydraulic integrity can be triggered by the same events that cause loss of physical integrity. For example loss of pipe pressure due to breach of hydraulic integrity increases the impacts of loss of physical integrity. Intermittent water supply affects water quality integrity by increasing water age and promoting biofilm growth (Besner, et al., 2011, Fontanazza, et al., 2015, WHO, 2014).

Presence of hazards and the occurrence of hazardous events, simultaneously contribute to risk. The risk for microbial contamination refers to the possibility of occurrence of an incident or situation that can lead to microbial contamination of drinking water. In the event of negligence, the physical integrity of the infrastructure, hydraulic integrity and/or water quality integrity are lost or compromised leading to low or negative pressures which in return can cause contaminant intrusion into the water mains given the right conditions (Besner, et al., 2011, Fontanazza, et al., 2015, Islam, et al., 2015, WHO, 2014).

Table 2.4-1 showing hazardous events in the distribution network (WHO, 2014).

Risk category	Hazardous event	Hazard
System construction and repairs		
Physical integrity	Contamination during construction of new water mains and renovation due to debris, vermin, soil, groundwater or rainwater entering an open pipe (not capped) or fitting while the pipe/fitting is on the truck, stacked in the store yard, lying beside the trench or in the trench before connection. Contamination of distribution system during new installations, including water meters, pumps, valve or hydrant insertions Debris, soil or groundwater remaining in the main after repairs and not removed during the main recharge operation	Microbial Chemical Physical
Hydraulic integrity	Sediment resuspension, sloughing of biofilms causing customer complaints due to incorrect valve operation (closed or opened) after repairs	Microbial Physical chemical
System operation		
Physical integrity	Corrosion leading to loss of structural integrity	M,P,C

Hydraulic integrity	Contamination from leaky water mains in areas of low pressure or intermittent water supply: ingress due to backflow through leaky joints, air valves, perforations Contamination from leaky sewer mains in areas of low pressure or with intermittent water supply: ingress due to backflow through leaky joints, Accumulation of biofilms, sediments and particles in water mains due to low flow velocities in pipes and resuspension during high-flow events Resuspension of biofilms, sediments, scales due to flow reversals	
Water quality integrity	Survival of pathogens, the growth of opportunistic pathogens and nuisance organisms in biofilms	microbial
Storage Tanks		
Physical integrity	Microbial contamination from the entry of birds and small animals or faeces through faults and gaps in: • roofs or hatches • overflow pipes and inlet control valves from upstream sources • air vents Ingress of contaminated groundwater from unsealed joints and cracks Security breaches from unauthorized access by humans, including vandalism, sabotage	Microbial physical
Water quality integrity	Sediment accumulation and biofilm growth at the bottom of the tank	microbial
Backflow		
Physical Integrity	Backflow from residential/industrial/commercial customers due to lack of prevention device or failure of the device; likelihood increased during low-pressure events in the water supply network Accidental cross-connection between drinking-water and non-drinking water assets during construction or maintenance, including opening a usually shut valve to allow recharging after repairs and failing to close after completion	Microbial Physical Chemical
Secondary disinfection		
Water quality integrity	Under-dosing of chlorine leading to inadequate protection against ingress of microbial contamination or growth of biofilms	Microbial

Chapter 3 Description of case study

3.1 General description

The study was conducted in Bushenyi-Ishaka municipality in Bushenyi district, which is located in Ankole sub-region of western Uganda Figure 2. Bushenyi district has a population of 251, 400 with 85% water supply coverage and 80% functionality. The water sources used in this area include boreholes, springs, rainwater, swamps and piped water supplies (Ministry of Water & Environment, 2018).

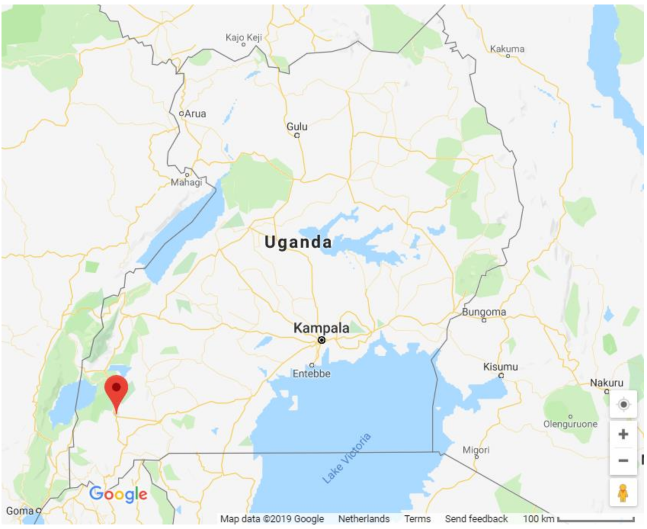

Figure 2 location of the study, Bushenyi-Ishaka municipality

The climate is classified as tropical wet and dry under Köppen and Geiger climate system (climate-data.org, 2019). Summers are much rainier than winters (driest month is July and the highest precipitation is in November). The average temperature in Bushenyi is 19.3 ^{o}C with an average rainfall of 1233 mm.

The study was carried out between November 2018 and January 2019, characterized by rainy afternoons and a few dry weather days and sunny days.

3.2 Bushenyi-Ishaka water supply system

Bushenyi water supply system, is the primary water supply system in Bushenyi district under National Water and Sewerage Corporation (NWSC). The NWSC is a public utility owned by the Ugandan government and is responsible for providing water and sewerage services in Uganda. It has a hierarchy management system where at district level it is managed by an Area Manager who is assisted by a Water Supply Superintendent, responsible for the technical services; Accounts Officer, responsible for the financial services; and a Commercial Officer, who interfaces with customers. Bushenyi, water supply system, is divided into smaller branches; each of them managed by a branch manager under the overall supervision of the area manager. The branches include Bushenyi-Ishaka Municipality, Kabwohe, Kitagata, Bugongi, Rubirizi, Kyabugimbi, Kashenshero, Mitooma, Kabira, and Buwheju. This study focuses specifically on the Ishaka area in Bushenyi-Ishaka municipality.

Bushenyi-Ishaka municipality has a total of 4,432 connections which is approximately 55% of its population. The typical consumer categories include public standpipes (PSPs), domestic household, institutional, governmental, industrial and commercial users. The consumer network has 123 PSPs, 3163 domestic connections, 157 institutional connections, and 989 commercial accounts. Currently, the Bushenyi-Ishaka network covers the municipal council areas of Rwentuha, Kyeizoba, Kibaare, Ntungamo, Kyabasenene, Bwera and Ncucumo. The network also extends to Uganda Technical College Kahaya on Mbarara Road and Butare on Kasese Road. However, massive extension of the distribution network is ongoing under the NWSC Service Coverage Acceleration Program (SCAP100), aimed at achieving 100% piped water coverage in 12,000 villages in 80 districts in Uganda by 2020 (NWSC, 2019).

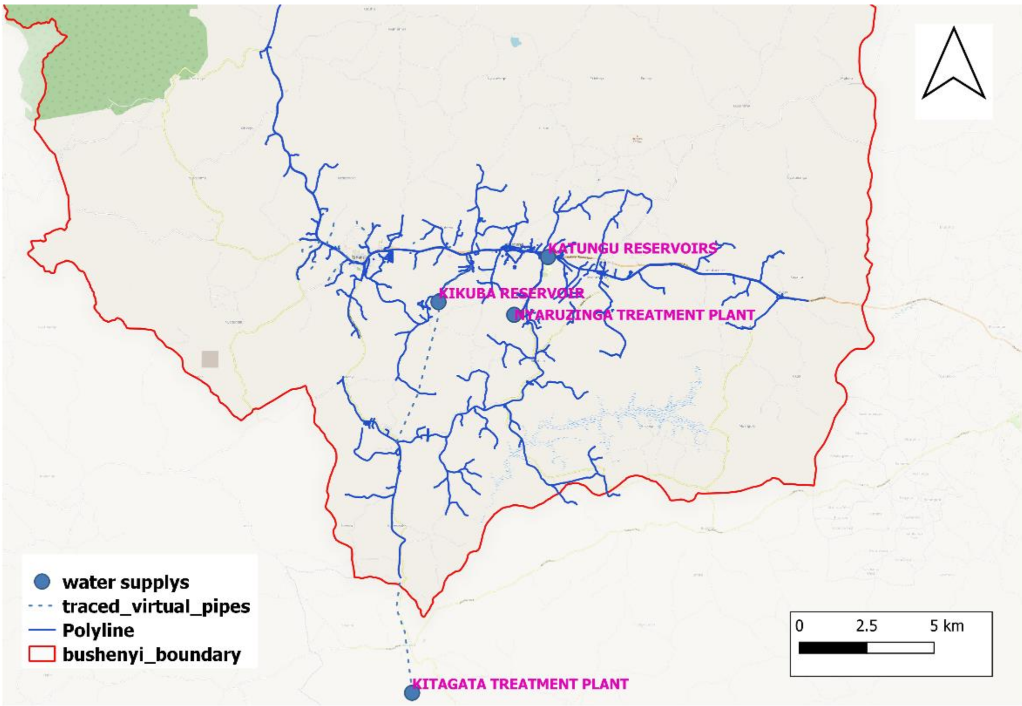

Figure 3 Map of the water distribution network in Bushenyi-Ishaka municipality

Bushenyi-Ishaka municipality is supplied by two sources that is Nyaruzinga wetlands and Njoga river each with an independent treatment plant; Nyaruzinga treatment plant and Kitagata treatment plant, respectively. The Kitagata treatment plant is the primary supply while Nyaruzinga treatment plant is used to supply Bumbaire line and as a back-up in case, Kitagata supply system has a problem. For example, in late January 2019 a burst on the main transmission line from Kitagata (as shown in Figure 4) interrupted the supply from this source for about two weeks. During this period, Nyaruzinga wetland was used to supply the whole system intermittently. Until early 2018, Nyaruzinga treatment plant was the sole supplier for

Bushenyi- Ishaka municipality water supply system. The water treatment plants have a conventional system consisting of pre-chlorination, aeration, pH correction with soda ash (lime), coagulation and flocculation (using alum and polymer), filtration and chlorination.

Figure 4 pipe laying during repair of a burst on the transmission mains in Kitagata

The raw water is abstracted from Nyaruzinga wetlands and treated at Nyaruzinga water treatment plant via a conventional treatment process. The water is then pumped to the two reservoirs at Katungu hills (270 m^3 each) for distribution by gravity. The average water production capacity of the plant is 1800 m^3/day. Due to the fast-growing population rate and growing water demand of the town and neighbouring areas, there has been a reduction in effectiveness of the waterworks and degradation of the distribution system with time hence provision of drinking water with poor quality. During the dry season, the water supply was intermittent (6 h/day) and continuous during the rainy season (NWSC, 2018).

To solve this problem, Kitagata Water treatment plant was constructed under Water Management Development Project (WMDP) funded by the World Bank between 2016 and 2018. It has an average production of 3500 m^3/day. Water is abstracted from Njoga River into an intake with mesh screens to prevent suspended matter from getting into the intake reservoir. The water is then pumped from the reservoir through perforated foot valves to the cascade aerator. Pre-chlorination (1 mg/L) is done immediately before the aeration. After aeration, the water flows directly into the coagulator where it is dosed with alum and a polymer. The water then flows into the flocculator to form bigger flocs. The flocculator has three stirrers but only one is in use. This is because when all the stirrers are used, the stirring is rapid leading to breakage of flocs and formation of small flocs. The water with flocs flows into the sedimentation tank flowing slowly to allow the flocs to settle. The operator mentioned that, when the temperatures are high, the flocs do not settle well leading to fast blockage of the filtration media and thus more backwash. From the sedimentation tank, the water flows into the rapid sand filtration tank, and into the clear water reservoir. Backwash is done every 24 hrs with air and water.

After disinfection, water is pumped into an elevated reservoir then supplied by gravity. The water is pumped to Kitagata reservoir (90 m^3) which serves Kitagata branch and to Kikuba reservoir (1600 m^3) which supplies Bushenyi-Ishaka municipality and Kabwohe branch. Kikuba reservoir is about 20 km away from the treatment plant which increases the water age before reaching the consumer taps. This leads to high chlorine consumption and thus makes the water highly vulnerable to microbial recontamination due to low residual disinfectant. Therefore, it was decided by the water quality team that water should be re-chlorinated at Kikuba reservoir before it is supplied into the distribution network. The water is then supplied into the WDN passing through a bulk meter to record the amount of water supplied into each line. The reservoir has two equal compartments with a floating meter that reads the level of the water in the reservoir to help avoid overflows. When the reservoir is full, the attendant communicates with the operator at the treatment plant to stop pumping water into the reservoir. It was mentioned that Kitagata reservoir should be cleaned once every three months.

The water distribution network for Bushenyi-Ishaka Municipality is approximately 400-500 km long. However, this study was focused on the Ishaka area which has about 100 km length of pipes. The pipes consist of various materials as shown in Figure 5, including asbestos cement (AC), polyethylene (PE), galvanized iron (GI), ductile iron (DI), steel (ST) and polyvinyl chloride (PVC) while the pipe diameters range between 0.75 – 10 (inches) (Nyakana, 2018, Twesigye, 2018).

Figure 5 different types of pipes used in the WDN of Bushenyi water supply system

Chapter 4 Materials and methods

This chapter describes the methodology that was used to carry out this research. For data collection, a mixed methods approach that involved both qualitative and quantitative methods was utilized. The methods include sanitary inspections, documentary review, semi-structured interviews, and water quality analysis. The water safety of the WDN of Bushenyi water supply network was evaluated through information collected from secondary sources (documentary review and interviews with the NWSC staff) and supported by primary data collection through observations during transect walks, sanitary inspections, and water quality monitoring. The data analysis approach for interpreting field data is also discussed.

4.1 Selection of study zone

A study zone of 12 villages adjacent to each other was selected (Figure 4.1-1 and 4.1-2). This was based on findings from the interviews with Bushenyi-Ishaka municipality NWSC staff, the number of connections per village according to the billing system, SMALL project household survey, and review of the customer complaints book. Twelve villages adjacent to each other were selected. The WDN is not physically zoned, and there is no existing map showing the villages. Therefore, the number of connections obtained by checking the national water billing system was not accurate. A total of 847 connections are located in the area of study.

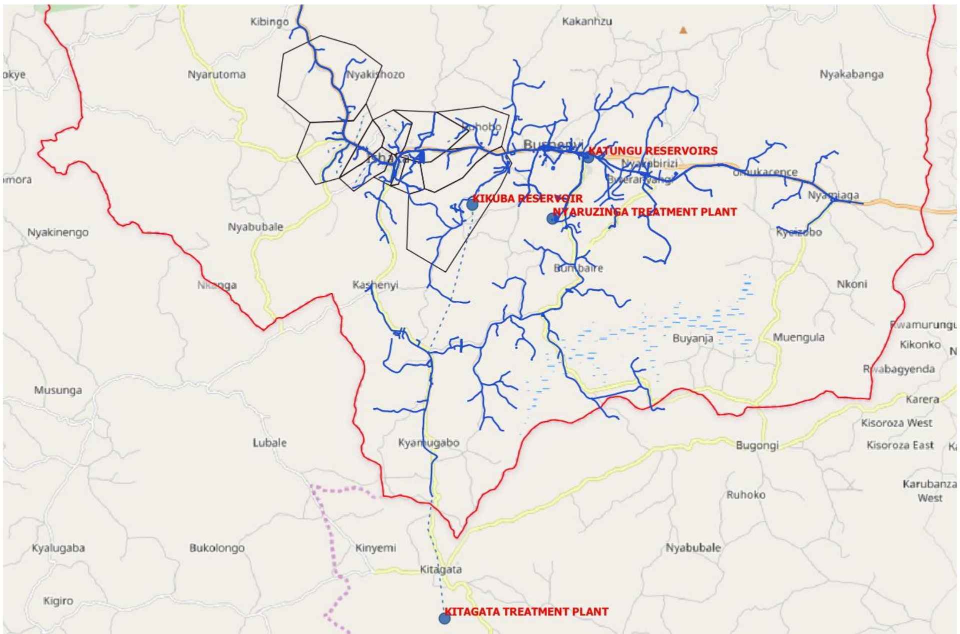

Figure 6 selected study zones (black contour)

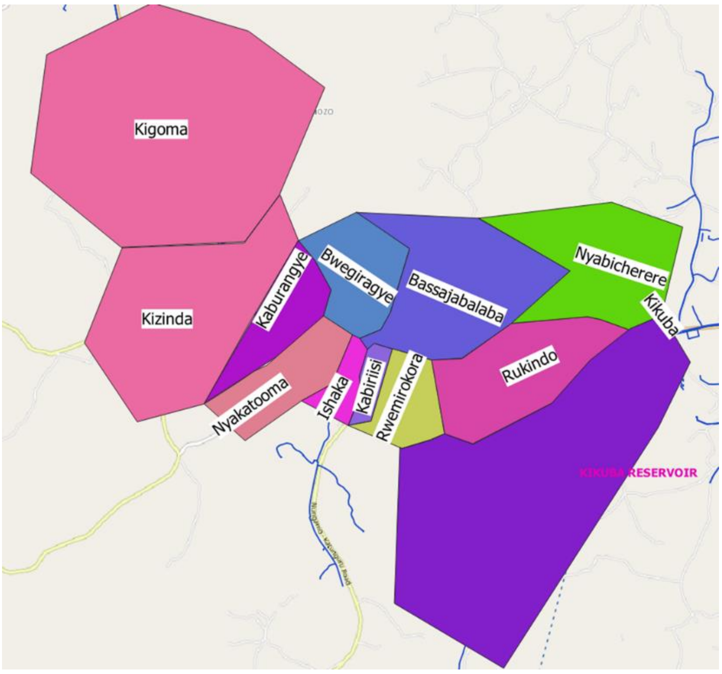

Figure 7 selected study zones with the names of the villages

4.2 Methods

4.2.1 Sanitary inspections

Sanitary inspections are observational tools for risk assessment which involve a semi-quantitative approach, based on semi-structured interviews with the NWSC staff, documentary review, and observations during the transect walks and water sampling. They targeted the physical structure of the water supply system, its operation, and external environmental factors. They were operationalized through SIFs which consisted of general data on the location, results of the last samples taken and weather conditions before and during the inspection, a section with instructions of use that must be read before using the SIF and then closed-ended sanitary inspection questions. Additional data like observations, photographs and recommendations were recorded on-site.

The closed-end questions have YES or NO answers. The YES answer indicates the presence of a risk factor while the NO answer indicates its absence. The SIF also provide a semi-quantitative classification of the level of risk of the particular hazard as follows:

• HIGH -very important, requires urgent attention and action;

• MEDIUM - important, requires attention and action may be taken;

• LOW - less important, no action required now.

In the case of the SIF for piped distribution, it contains 17 questions that specifically target the reservoirs, tap stands (public standpipes and private yard taps), and general external environment of the WDN as shown in Table 4.2-1. Find the full SIF attached in the Appendices.

Table 4.2-1 checklist questions as they appear in the SIF (WHO, 2018)

No.	Question		No	Yes	Level of risk	Action needed
Reservoirs (including storage tanks)						
1.	Is the reservoir open (i.e., uncovered), or if there is a cover, is it inadequate (e.g., cracked, damaged, leaking) to prevent contamination?					
2.	Is the reservoir structure damaged, cracked or leaking?					
3.	Is there any point of entry (e.g., air vent, overflow pipe, inspection hatch cover) to the reservoir that is inadequately covered or sealed to prevent contamination from entering?					
4.	Does the inside of the reservoir contain any visible signs of contamination (e.g., animal waste, sediment accumulation, scum, floating objects)?					
5.	Can water short-circuit from the inlet to outlet?					
6.	Is the fencing or barrier around the reservoir absent or inadequate to prevent contamination or unauthorized entry?					
7.	Can signs of sources of pollution be seen within 10 meters of the reservoir (e.g., latrines, animals, rubbish, open defecation)?					
Public tap stands/private yard taps						
8.	Are the tap stand/tap attachments (such as hoses etc.) unclean, damaged or leaking?					
9.	Is the drainage poor (e.g., absent or inadequate drainage channel), causing stagnant water in the tap stand/tap area?					
10.	Is the concrete floor around the tap stand/tap absent or inadequate to prevent contamination (e.g. cracked, damaged)?					
11.	Is the fencing or barrier around the tap stand/tap absent or inadequate to prevent contamination or unauthorized entry?					
12.	Can signs of sources of pollution be seen within 10 meters of the tap stand/tap (e.g. latrines, animals, rubbish, open defecation)?					
General						
13.	If there are any pressure break boxes/tanks, are their covers absent or inadequate to prevent contamination?					
14.	Are there any leakages visible between entry point to the distribution system and the point of delivery to the user (e.g. leaking pipes or valves, ponding water etc.)?					
15.	Are there any visible signs of illegal connections to the distribution system network?					
16.	Are there any exposed pipes visible in the system?					
17.	Are there any signs of erosion within the system that may compromise the integrity of any of the system components (e.g. near to pipes, break pressure boxes, values, reservoirs etc.)?					

The risk level was classified as low, medium or high based on both severity and frequency of occurrence of the risks. SIFs were used to identify potential sources and pathways for faecal contamination on the Ishaka branch water distribution network and to quantify the risks through the risk scores Figure 8. These were observed through transect walks and during sampling around the tap stands. Any other comments about the risks were written in a notebook for later consideration when filling out the SIFs.

In this case study, there was one common reservoir for the whole system; hence the sanitary inspection at the reservoir was carried out once. Twelve sanitary inspections were carried out at the village scale, five at the medium scale of a combination of villages fed by the same main and one general sanitary inspection for the whole area of study. This was done for later comparison and see at which scale the sanitary inspections work more appropriately.

Enter the number of 'Low', 'Medium', 'High' risks and multiply by the relevant number to generate a 'Score'. The sum of the three scores is the 'Sanitary risk score'.			
Risk level	**Number of risks**	**Multiply by:**	**Score**
# High		X 5	
# Medium		X 3	
# Low		X 1	
Sanitary risk score (max. 65)		**Total:**	

Figure 8 the risk matrix used for calculating risk scores

4.2.2 Transect walks and observation

The transect walks involved systematic walks along the transmission mains and the secondary distribution pipes per village. This was done as an initial survey before the collection of water samples. This helped in the identification of potential sources of contamination and hazardous events in the WDN. Also, during these walks, the sampling points (tap stands) were selected for later water sampling. The photographs of the identified risks were taken, and the associated GPS coordinates per risk were recorded. All observations were recorded in a notebook.

4.2.3 Documentary review

The documentary review involved going through the customer complaints book. This book was conceived through the customer complaint management system which was installed to help solve customer complaints and improve customer trust. It contains all kinds of complaints reported by customers or observed by staff during field visits. This book is designed in the form of a table with columns to fill, the complaint, details of the person reporting, the location of the problem, time and date of report, the person assigned to solve the problem, time of completion and type of solution applied and a signature. The branch manager follows up to ensure the problem is solved in time. However, the focus of this study was to find out the history of hazards and hazardous events such as bursts, leakages, repairs, and past consumer complaints on water quality.

The complaints from January 2018 to October 2018 were reviewed during this study. The complaints of interest were divided into themes of importance to this study i.e. history of bursts and leakages, past water quality problems, reports of lack of supply and pressure in the WDN. This data helped carry out a scoping study which in turn helped in the selection of the study zone.

4.2.4 Interviews

Interviews were held with the NWSC staff as part of the scoping study to complement the information obtained through documentary review, get a better understanding of the WDN and the supply system on general and also to aid in the selection of the study zone. The interviews were scheduled with the interviewees after review of the customer complaint book and a few field visits with the technical team to understand the WDN. The interviewees included the technical manager, commercial officer, customer sensitization personnel, water quality personnel and plant operator. The content of the interviews is as shown in the Appendices.

4.2.5 Water quality monitoring

Water quality monitoring was carried out in the selected zones based on the hazards and vulnerability factors to check for the impact of pathogen intrusion on the water quality. The parameters tested include:

- *E. coli*
- Turbidity
- pH
- Free residual chlorine

E. coli is a priority indicator because it indicates the presence of faecal contamination and thus shows the potential presence of pathogens. Turbidity, pH and residual chlorine will be monitored because they influence the microbial quality of water.

4.2.6 Sampling strategy

Sampling was done within a period of 3 months (November 2018 – January 2019). Due to lack of proper understanding of the location of connections and the physical boundary separating the villages convenience sampling was carried out aimed at covering the intended area, and a total of 169 samples were collected. The sampling points were selected per village (as shown in Table 4.2-2). The sampling points were distributed at least at a distance of 100 m from each other.

During sampling, hazards and hazardous events around the tap stands were identified such as the presence of rubbish, latrine, animals, exposed pipes and leakages. For every sample collected, it was analyzed for *E. coli* , pH, turbidity, and chlorine residual.

Table 4.2-2 showing the number of connections and sampling points per village

Location/villages	Number of connections	Number of sampling points per village
Bwegiragye	67	12
Bassajabalaba	78	15
Kizinda	168	28
Ishaka	50	8
Kigoma	35	6
Nyakatooma	98	15
Rwemirokora	130	12
Kaburangye	30	5
Kabiriisi	76	13
Nyabicherere	50	23
Rukindo	22	20
Kikuba	43	12
TOTAL	**847**	**169**

4.2.7 Sampling methods

During sampling, the water was allowed to run for 1-3 minute to allow consistency before grabbing a sample. In order to prevent self-contamination, the sampling point was sterilized by cleaning with a clean tissue soaked with ethanol 70% before samples were grabbed. Samples for microbiological analyses were collected in 100 mL sterile bags containing sodium thiosulfate to neutralize residual chlorine. The samples for *E. coli* analysis were stored in a cooler box to maintain the temperature of the sample, to keep it from being tampered with and for easy transportation.

Samples for physicochemical analyses were collected in 100 mL plastic sampling bags. The free chlorine analysis was done in-situ while for turbidity and pH was done in the laboratory. The time between sampling and analysis of these samples was kept at a minimum to avoid water quality degradation. The records for the sampling details were well stored with back up in case of data loss. During sampling, field measurements were recorded immediately, observations and deviations too. Excel datasheets were developed to fill out the measurements carried out in the field. Each sample collected to be analyzed in the laboratory was well labeled as follows:

- Sampling location
- Sampling code
- Date and time of sampling

4.2.8 Analytical methods

Escherichia coli

E.coli was tested using the membrane filtration method with a Palintest filtration unit. Nutrient Pad Sets (Sartorius), which consist of dehydrated Chromocult media pads in Petri dishes, were used to culture the bacteria. Labelling of the agar plates was done with sampling codes. The media was rehydrated with 3.0 mL of sterile and demineralized water. Sterile forceps were used to place the membrane filter of 47 mm diameter and 0.45µm pore size with the grid-side up on the filtration device. To avoid self-contamination, the forceps were sterilized by Dipping in boiling water and left for some time and with ethanol for each sample. 50 mL duplicate samples were filtered, then the membrane filter was placed on Chromocult agar and incubated for 18-24 hours at a constant temperature of 37^0C in an incubator.

pH

The analysis of pH was done using the HQ40d portable multi-meter with a Gel Electrode and a cable according to the manufacturer’s handbook. The calibration of the pH meter was done monthly using a buffer seven and ten solutions. The Gel electrode was preserved by putting potassium permanganate solution in the lid to ensure that it does not stay dry.

Turbidity

Turbidity was measured using the 2100P portable turbidimeter. In the analysis of turbidity, clean sample vials provided in the kit were used. The sample was poured into the sample vial to the 10 mL mark and capped. The sample vial was cleaned outside using a tissue to ensure that all marks and fingerprints are removed. The sample vial was placed into the instrument to read the turbidity.

Free Chlorine

Free chlorine ($HOCl$, OCl^-) was measured using HACH DR/890 pocket colorimeter. A 10 mL sample cell was filled to the mark. Then HACH DPD 1(diethyl-p-phenylenediamine) powder pillow was added into the sample, and the colour was allowed to develop for 3 minutes using the colorimeter timer. The water turns to a shade of pink, the pinker the water, the more the chlorine present. Field blanks will be used to zero the equipment before the readings are taken. The colorimeter then carries out a colorimetric analysis of the sample and returns a value of residual chlorine in mg/l. To avoid contamination through the demineralized water, all the demineralized water used during this study was filtered using Steri-cups (Merk). Every batch of filtered demineralized water was plated as a blank to ensure there is no contamination.

4.3 Data analysis and interpretation

Data collected from the field were stored in Microsoft Excel. The SIF checklist questions were entered in excel sheets for easy calculation of the sanitary risk scores. The hazards and the hazardous events identified per village were categorized as low, medium and high) risk depending on the severity and probability of it causing microbiological contamination. The risks of the SIFs carried out were then scored to yield sanitary risk scores using the risks matrix as shown in Figure 8.

The *E. coli* concentration was classified based on the number of coliforms per sample (0-conformity with WHO guideline, 1-10-low risk, 11-100 intermediate risk, >100-high risk) as shown in Table 4.3-1. The sanitary risk scores were classified based on the sanitary risks with a maximum of 65 (0-no risk, low risk 1-20 intermediate risk 21-40, high risk 41-65) as shown in Table 4.3-2. This classification was done to be able to correlate the sanitary risk scores and the *E. coli* concentration in a risk matrix.

Table 4.3-1 risk classification of *E. coli* concentration (WHO, 1997)

***E. coli* concentrations**		**Risk classification scheme**
0 CFU/100mL	A(green)	In conformity with WHO guidelines
0.5-10 CFU/100mL	B (yellow)	Low risk
11-100 CFU/10mL	C (orange)	Intermediate risk
>100 CFU/100mL	D (red)	High risk

Table 4.3-2 risk classification for sanitary risk scores (WHO, 1997)

Risk scores	**Risk classification scheme**
0	no risk
1-20	Low risk
21-40	Intermediate risk
41-65	High risk

The statistical analysis was performed using the Statistical Package for Social Sciences version 20.0 (SPSS) and MS excel real statistics pack. The box plots for showing the variability of water quality data were plotted using SPSS. Box plots were used to visualize the descriptive distribution and range of water quality data. The box plot is divided into four quarters each of 25%. It shows points outside the box plots represent the minimum value (lower whisker), median (a line across the middle of the plot) and the maximum value (upper whisker) while the circles outside the box plot represent the outliers while asterisks represent the extreme outliers. In the course of this study, the extreme outliers were excluded from the graph for better visualization of the data.

A non-parametric Kruskal-Wallis test was carried out using Excel real statistics pack, to determine if there are statistically significant differences between *E. coli* concentrations in different areas of consideration.

Spearman's Rho Correlation analyses were performed to determine the statistical relationships between sanitary risk score and *E. coli* concentration. The *E. coli* concentration for each sampling point and its risk score were input as variables, a Spearman's correlation coefficient was obtained and a 2-tailed significance. A positive correlation coefficient indicates a positive relationship between the two variables (as values of one variable increase, values of the other variable also increase) while a negative correlation coefficient expresses a negative relationship (as values of one variable increase, values of the other variable decrease). A correlation coefficient of zero indicates that no relationship exists between the variables. The threshold for statistical significance was set at $p < 0.05$.

The predictive value was determined using a logistics regression model and ROC curve using SPSS (Snoad, et al., 2017). The logistic regression model gives results as shown in Table 4.3-3

Table 4.3-3 logistic regression model output

Observed		**Predicted**		
		Status		**Percentage Correct**
		0	**1**	
***E. coli* concentration**	**Absent**	True negatives	False negatives	Negative predictive value
	Present	False positives	True positive	Positive predictive value
Overall Percentage				**Average predictive value**

The following values were calculated:

- True positive (TP) = correctly identified
- False positive (FP) = incorrectly identified
- True negative (TN) = correctly rejected
- False negative (FN) = incorrectly rejected
- True positive rate or sensitivity (TPR) is the true positives divided by the sum of true positives and false negatives.

- True negative rate or specificity (TNR) is the true negatives divided by the sum of true negatives and false positives.
- Negative predictive value (NPV) is the true negatives divided by the sum of true negatives and false negatives.
- Positive predictive value (PPV) is the true positives divided by the sum of the true positive and false positive.

Receiver operating characteristic (ROC) curve was used to determine the accuracy of the predictive value of sanitary inspections and also to visualize the area under the curve (AUC This was done by plotting a curve of sensitivity against false positive rate (1-specificity). When the AUC is close to 1 the better the accuracy of the model while if the AUC is 0.5 it means the model cannot discriminate between positives and negatives. For each sample, the presence of *E. coli* concentration was represented by one while its absence was represented by zero. The risk scores were input as the test variable while the *E. coli* concentration was input as the state variable.

Chapter 5 Results and Discussion

5.1 Results

5.1.1 Scoping study

Before starting the implementation of SIFs and water quality monitoring, it was essential to carry out a scoping study to make more informed decisions while selecting the study zone. This involved understanding the network by going to field with the technical team, reviewing customer complaints book at the NWSC Katungu office, and interviews with the NWSC Bushenyi-Ishaka municipality staff as mentioned in 4.2.4. During this period of study, the main focus was to understand the WDN, gain knowledge on the history of hazards and hazardous events in the WDN and their associated risks and also to understand the control measures taken towards mitigating them.

Generally, based on information gathered from the customer complaints book review and the interviews, the causes of leakages are bursts due to high pressures in the network; exposed pipes are cut during farming, illegal connections, breakage by curious kids, accidental cutting during trenching for new pipe installations and during road construction and maintenance, faulty meters, and shoddy workmanship. The leading causes of leakage are bursts due to ageing pipes and cutting of pipes during road construction and maintenance. The most vulnerable pipes to bursts are the old asbestos cement transmission mains. Currently, the NRW stands at 27% according to the technical manager. To reduce leakage, response time to leakage reports has been minimized, fast replacement of faulty meters, increased vigilance on water theft and reduced overflows at the reservoir.

According to the interviews, there are no pressure sensors in the system and no pressure control valves due to financial constraints. During construction of the secondary distribution network, the elevations of pipes and ground levels are not checked. Instead, they are checked when water does not reach the intended outlets. The villages with many cases of low pressure in the distribution are hilly areas.

Furthermore, it was mentioned that the Ishaka branch had high intermittency in 2018 after the change of the supply system. Currently, most of the cases of lack of water are due to customers closing the gate valve ignorantly, low pressures in the distribution line, and main breaks/leakages. The areas with complaints of no supply are Kanyamabona, Kaburangye, Bwegiragye, Kashenyi, Ibaare, Bumbaire, and Muhirwe A.

According to the customer complaints book, in some instances, the water was highly turbid and coloured. It stained clothes if used for washing, and when stored in a jerry can, it had brown deposits forming at the bottom. Water quality complaints cases reduced gradually throughout

2018 as seen through the review of the customer complaint book. According to the interviews, after installation of the new plant in Kitagata, the quality of water improved immensely leading to reduced reports on water quality problems have reduced. According to the technical manager, the leading causes of poor water quality at the consumer tap stands is sporadic cleaning of overhead tanks by the consumer and bursts and leakages that take long to be discovered. The areas with many water quality complaints are Kyamuhunga, Kigoma and Ishaka market. To curb the problem of turbid water, flushing is often done to clean out the system. According to the technical manager, flushing is done once every two months, but in case of reports of dirty water, the washouts are opened to flush out the dirt from that specific line.

5.1.2 Drinking water quality

One hundred sixty-nine samples were collected each from different tap stands in Ishaka branch, all distributed in 12 villages. All the tap stands sampled are installed by NWSC and a part of Bushenyi-Ishaka water supply system. Kikuba reservoir was also sampled once a week to check the quality of water supplied into the distribution network.

Water quality in the reservoir

The samples collected at Kikuba reservoir were analyzed for *E. coli*, turbidity, pH and free chlorine. From the obtained results (as shown in Table 5.1-1), the residual chlorine was very low before installation of the chlorine booster station. The chlorine residual improved significantly when booster chlorination was implemented at the reservoir in late January 2019 this can be seen from the sample collected on 02 February 2019.The pH level increased gradually throughout the sampling period. However, on 10th December 2018, the pH at the reservoir was 4.5 which is highly acidic while the chlorine residual on the same day was 0.48 mg/L. The turbidity was less than 5 NTU throughout the sampling period. The *E. coli* concentration also maintained at 0 CFU/100 mL except for on 16th January 2019 when the *E. coli* concentration was 6 CFU/100 mL.

Table 5.1-1 water quality in the reservoir

Date of sampling	Free chlorine (mg/L)	pH	Turbidity (NTU)	*E. coli* (CFU/100 mL)
08/11/2018	0.10	5.7	2.0	0
23/11/2018	0.17	6.9	0.7	0
06/12/2018	0.26	6.7	1.9	0
10/01/2019	0.48	4.5	1.4	0
16/01/2019	0.17	7.0	2.0	6
02/02/2019	1.02	7.0	2.1	0

Microbiological contamination

The *E. coli* concentration ranged between 0 -1264 CFU/100 mL. However, the concentrations are not evenly distributed to this range as 95% of the samples had *E. coli* concentrations ranging between 0 - 65 CFU/100 mL. According to Table 5.1-2, 44% of the samples tested negative for *E. coli* hence conform to WHO guidelines, 31% had a range of 1-10 CFU/100 mL which is classified as low risk, 22% had a range of 11-100 CFU/100 mL which is classified as intermediate risk, and 3% had 101-1264 CFU/100 mL under high risk classification. A total of 95 samples tested positive for *E. coli* CFU/100 mL.

Table 5.1-2 risk classification associated to *E. coli* concentration in water samples

***E. coli* concentration**		**Risk classification scheme**
0 CFU/100 mL	44% (74/169)	In conformity with WHO guidelines
0.5-10 CFU/100 mL	31 % (52/169)	Low risk
11-100 CFU/100 mL	22% (38/169)	Intermediate risk
>100 CFU/100 mL	3% (5/169)	high risk

According to Table 5.1-3, at a medium scale, AREA 2 has the lowest number of samples with *E. coli* concentration (40%) where ten samples are classified under low risk, five samples under intermediate risk and two samples under high risk. AREA 3 has the most significant number of samples positive to faecal contamination (72%) where 14 samples are classified under low risk and 12 samples under intermediate risk and two samples under high risk category. AREA 1, AREA 4 and AREA 5 have 58%, 57% and 57% of samples with *E. coli* concentrations respectively.

Table 5.1-3 risk classification at medium scale

Locations	**Villages**	**0 CFU/100 mL No risk**	**0.5-10 CFU/100 mL Low risk**	**11-100 CFU/100 mL Intermediate risk**	**>100 CFU/100 mL High risk**	**% of samples positive to *E. coli***	**Total**
AREA 1	Kikuba	5	3	4	0	**58%**	**12**
AREA 2	Nyabicherere Rukindo	26	10	5	2	**40%**	**43**
AREA 3	Bassajabalaba Bwegiragye Rwemirokora	11	14	12	2	**72%**	**39**
AREA 4	Ishaka Kabiriisi	9	5	6	1	**57%**	**21**
AREA 5	Nyakatooma Kigoma	23	20	11	0	**57%**	**54**

From Table 5.1-4, the number of samples per risk classification reduces progressively from low risk to high risk. 100% of the samples in Bwegiragye had *E. coli* concentration, while 100% of the samples from Kaburangye village conform to WHO guidelines. Generally, Bassajabalaba, Kabiriisi, Kaburangye, Nyabicherere, and Nyakatooma villages have few contaminated samples <50%.

Table 5.1-4 showing the risk classification at the village scale

	0 CFU/100 mL No risk	**1-10 CFU/100 mL Low risk**	**11-100 CFU/100 mL Intermediate risk**	**>100 CFU/100 mL High risk**	**% of samples positive to *E. coli***	**TOTAL**
Bassajabalaba	9	4	2	0	40%	**15**
Bwegiragye	0	7	4	1	100%	**12**
Ishaka	1	3	4	0	88%	**8**
Kabiriisi	8	2	2	1	38%	**13**
Kaburangye	5	0	0	0	0%	**5**
Kigoma	1	5	0	0	83%	**6**
Kikuba	5	3	4	0	58%	**12**
Kizinda	7	10	11	0	75%	**28**
Nyabicherere	18	0	4	1	22%	**23**
Nyakatooma	10	5	0	0	33%	**15**
Rukindo	8	10	1	1	60%	**20**
Rwemirokora	2	3	6	1	83%	**12**
TOTAL	**74**	**52**	**38**	**5**	**56%**	**169**
	44%	**31%**	**22%**	**3%**	**56%**	

From the map Figure 9, the *E. coli* concentration can be visualized. The sampling points are indicated by the points in green, yellow, orange and red according to Figure 9. It is evident that most of the sampling points in Kaburangye, Nyakatooma, and Nyabicherere have 0 CFU/100 mL while many samples in Kizinda, Bwegiragye and Ishaka show the presence of *E. coli* CFU/100 mL. This agrees with the results shown in Table 5.1-4.

It can also be seen that, in some villages like Bassajabalaba and Nyakatooma, the samples from the same pipeline some were not contaminated while others were highly contaminated. In other cases like Bwegiragye and Kizinda, all samples from the same secondary main were contaminated. It is also evident that most samples from urban centres such as Ishaka, Kizinda and St. Kaggwa market centre in Nyabicherere were contaminated.

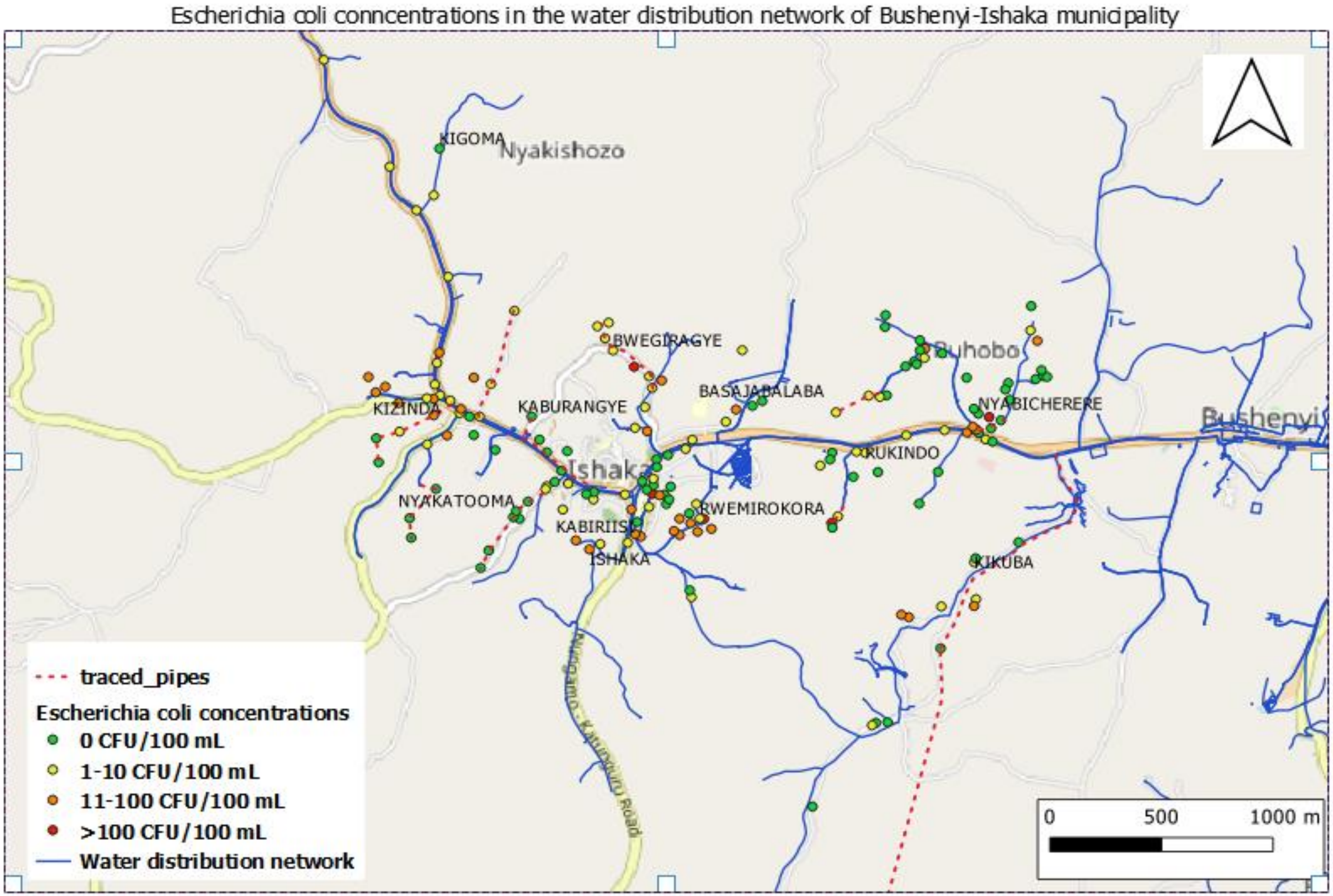

Figure 9 map of *E. coli* concentrations in the samples collected

Village scale

For better visualization of the distribution, the extreme outliers (<100CFU/100 mL) were presented as 101 CFU/100 mL. According to the box plot shown in Figure 10 the *E. coli* concentrations in the upper quartiles shows high variability compared to the lower quartiles in all villages. The upper whiskers are more prolonged than lower whiskers which depict that data is positively skewed. Kaburangye and Nyabicherere villages have a similar distribution of E. *coli* concentrations. The lowest median is 0 CFU/100 mL in Bassajabalaba, Kabiriisi, Kaburangye, Nyabicherere, and Nyakatooma villages but these villages have a different distribution of *E. coli* concentration. Rwemirokora has the highest median of 13.5 CFU/100 mL among the villages.

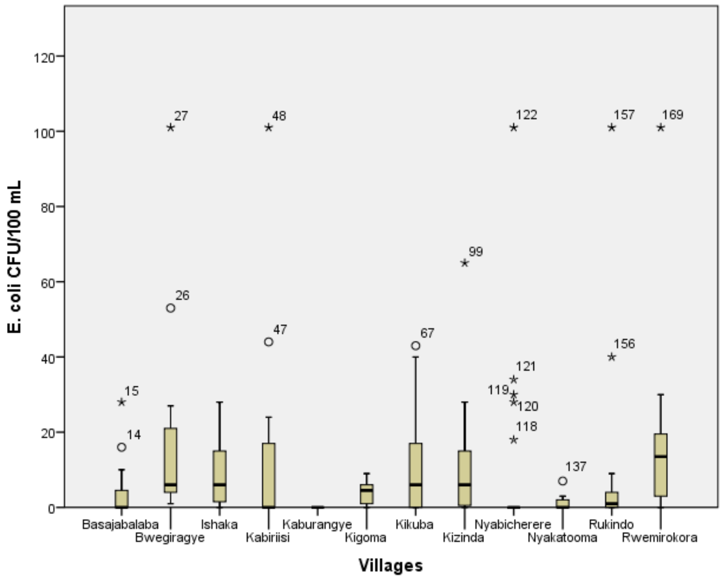

Figure 10 box plots showing *E. coli* concentrations at the village scale

Kruskal-Wallis Test was conducted to examine the differences in *E. coli* concentrations at the village scale. According to Table 5.1-5, there was a significant difference in the median values of *E. coli* concentration among the villages. The p-value is 0.0007 which is less than the alpha = 0.05.

Table 5.1-5 Kruskal-Wallis results for *E. coli* concentrations per village

	median	**rank sum**	**count**	**r^2/n**	**H-stat**	**H-ties**	**df**	**p-value**	**alpha**	**sig**
Bassajabalaba	0	1054	15	74061.07						
Bwegiragye	6	1361	12	154360.08						
Ishaka	12	977.5	8	106167.36						
Kabiriisi	0	897.5	13	67125.52						
Kaburangye	0	187.5	5	7031.25						
Kigoma	4.5	528	6	46464						
Kikuba	6	1069	12	95230.08						
Kizinda	6	2922.5	28	305035.94						
Nyabicherere	0	1435	23	89531.52						
Nyakatooma	0	897	15	53640.6						
Rukindo	1	1601	20	128160.05						
Rwemirokora	13.5	1435	12	171602.08						
			169	1298409.56	32.11	38.3	11	7.04369E-05	0.05	yes

Medium scale

For better visualization of the distribution, the extreme outliers (<100CFU/100 mL) were presented as 101 CFU/100 mL. According to the box plot shown in Figure 11, the general distribution of the *E. coli* concentrations is similar in the lower quartile and varies significantly in the uppermost quartile. AREA 3 has the highest median while AREA 2 has the lowest median. AREA 4 and AREA 5 have equal median values but with a different distribution. AREA 2 has the highest number of outliers.

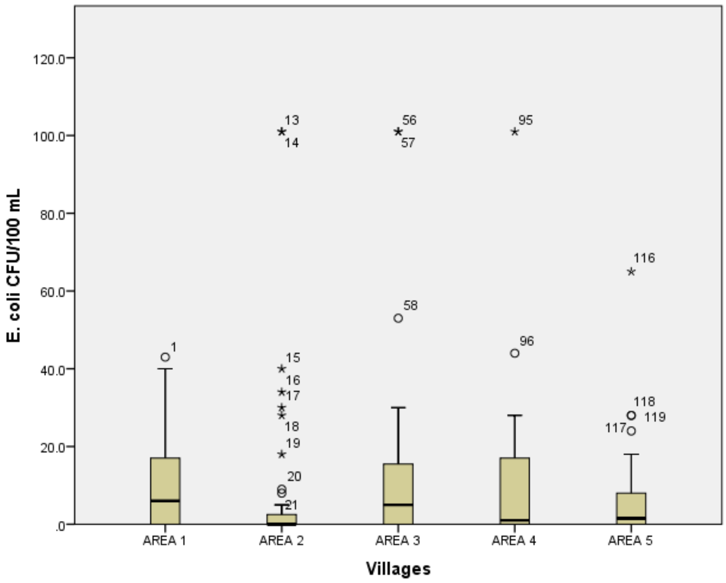

Figure 11 box pots showing *E. coli* concentrations at a medium scale

Kruskal-Wallis Test was conducted to examine the differences in *E. coli* concentrations at a medium scale. According to Table 5.1-6, the p-value = 0.06 which is higher than the alpha 0.05; hence there was no significant difference in the median of *E. coli* concentration among the areas in medium scale.

Table 5.1-6 Kruskal-Wallis results for *E. coli* concentrations at a medium scale

	AREA 1	**AREA 2**	**AREA 3**	**AREA 4**	**AREA 5**	
median	6	0	5	1	1.5	
rank sum	1140.5	3045	4015.5	1843.5	4490.5	
count	12	43	40	21	54	170
r^2/n	108395.21	215628.49	403106.01	161832.96	373418.34	1262380.82
H-stat						8.11
H-ties						8.86
df						4
p-value						0.06
alpha						0.05
sig						no

Physical characteristics

Turbidity was used to measure the clarity of water through the amount of light that is scattered by particles in the water when a light is shined through the water sample. According to WHO, the threshold for turbidity in potable water should be 5 NTU; the water was thus considered turbid when it exceeded turbidity of 5 NTU. The turbidity values ranged between 0.6-91 NTU. Out of 169 samples, 29 (17.2%) samples had turbidity above 5 NTU. Nyabicherere village showed the most significant variability in turbidity levels ranging from 1 NTU to 91 NTU. The turbidity values from Kaburangye, Kigoma, and Nyakatooma had similar distribution and within the threshold of 5 NTU.

For better visualization, the turbidity values >20 NTU are excluded from the boxplot. However, the box plot in Figure 12 shows Nyabicherere and Bassajabalaba had the most varying turbidity levels while Kaburangye had the least variation. The highest median value is in Bassajabalaba while the lowest is in Kaburangye. It is notable that the median turbidity levels in all villages are < 5 NTU.

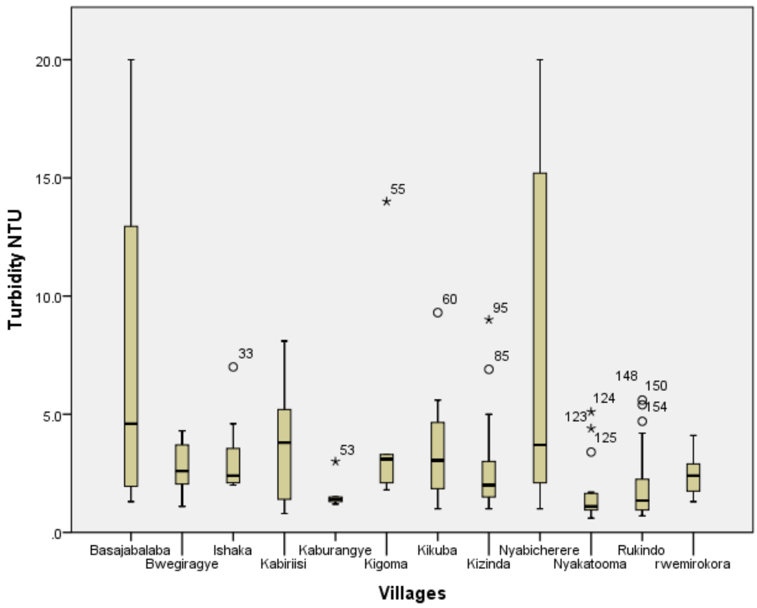

Figure 12 box plots showing turbidity levels at the village scale

Figure 13 depicts that, all the areas at medium scale have median value < 5 NTU. AREA 2 and AREA 5 have many outliers. AREA 3 has a low variation in data distribution and also has the highest mean value. It is noticeable that area 2 which is a combination of Nyabicherere and Rukindo, has the highest variation in data.

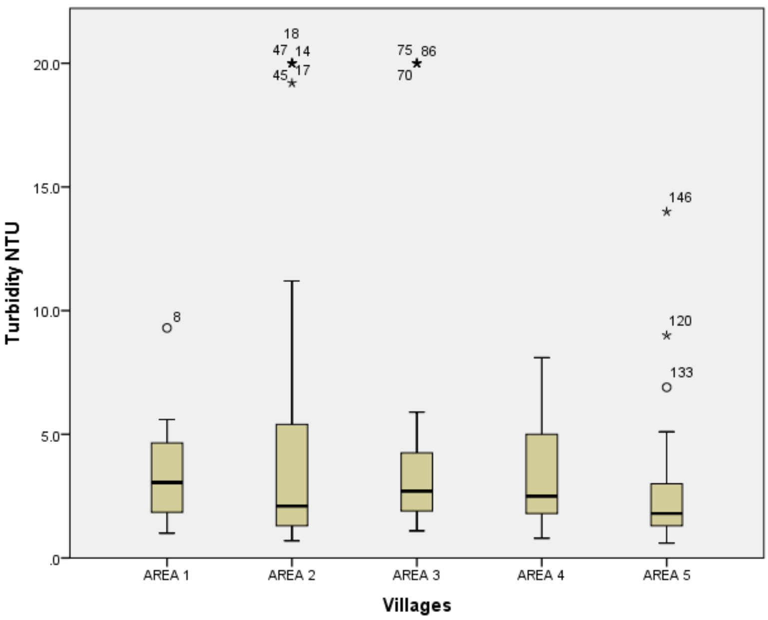

Figure 13 box plots showing turbidity levels at medium scale

Chemical parameters

pH

pH was used to measure the acidity or the alkalinity of the water. According to the graph in Figure 14, the pH values ranged between 5.2 and 7.4. Out of 169 samples, 135 samples (80%) had a pH value lower than 7, 18 samples (10.6%) had a neutral pH value while 16 samples (9.4%) had a pH value above 7. It is important to note that most outliers have a pH value below 6. The pH values of Bassajabalaba, Bwegiragye, and Nyabicherere vary significantly compared to those of other villages. Kaburangye has pH values with a median of about 7.

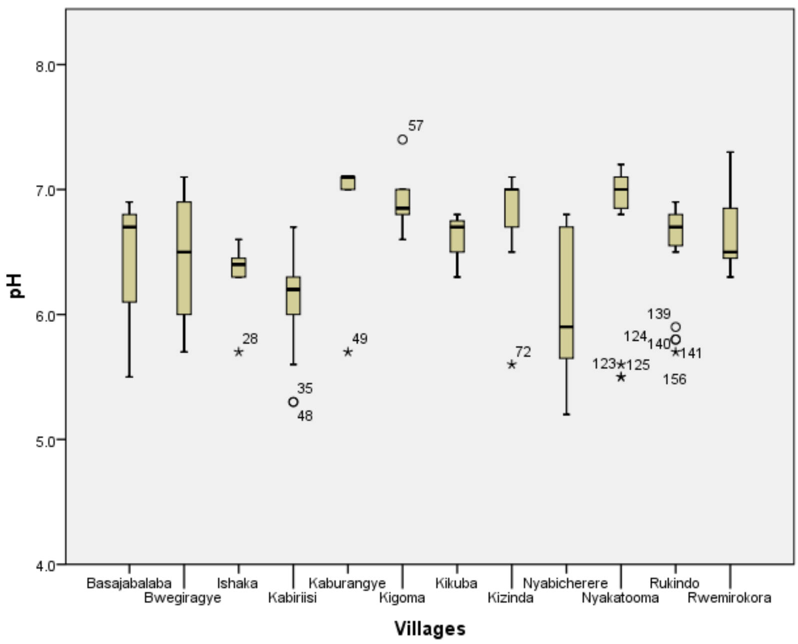

Figure 14 a box plot of pH values at village scale

The median values of pH are between 6.5-7 for all areas. The pH values of samples from AREA 1 are highly uniform compared to AREA 2 and 3 which show high variance. AREA 5 shows to have higher median of about 7 compared to other areas. See Figure 15.

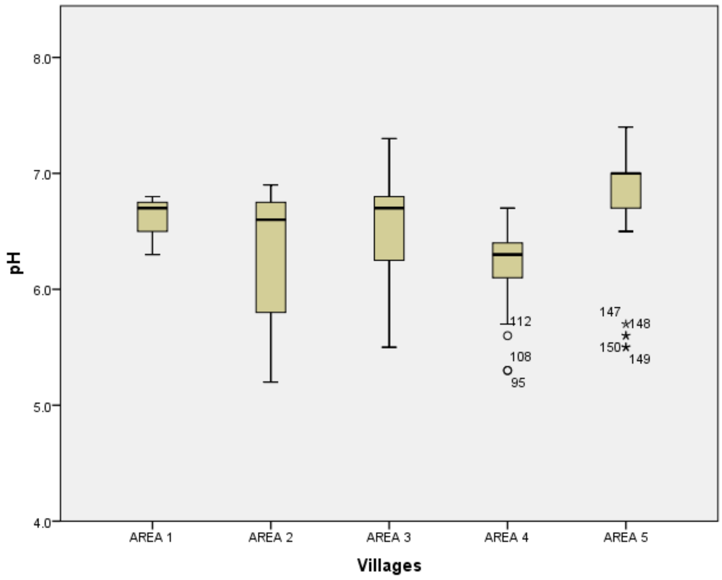

Figure 15 box plots of pH at medium scale

Free Chlorine

The maximum and the minimum allowable free chlorine in drinking water by the WHO is 5 mg/L and 0.2 mg/L, respectively. As seen in Figure 16, the residual chlorine for all samples ranges between 0-0.7 mg/L. Out of 169 samples, 128 (76%) samples had residual chlorine below 0.2 mg/L at the consumer outlets while 41 (24%) samples had chlorine residual above 0.2 mg/L.

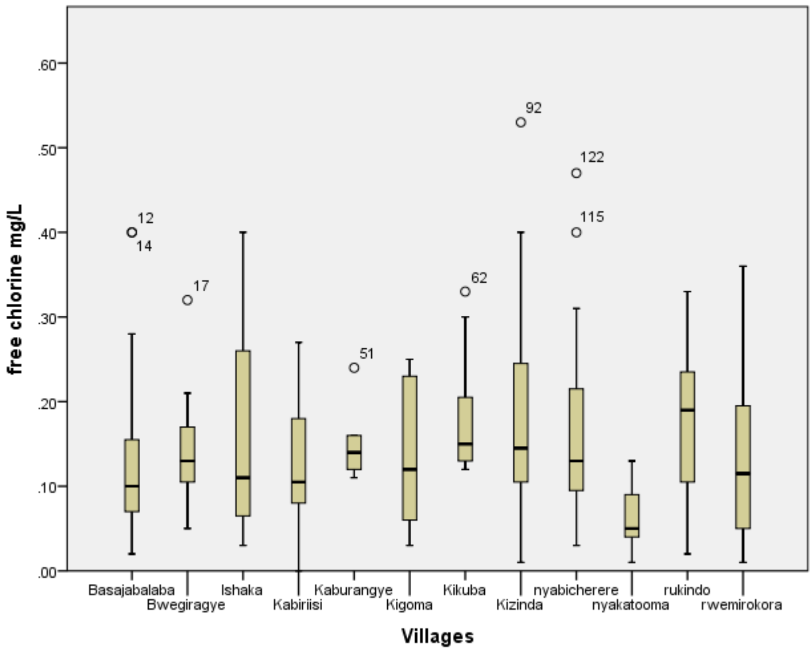

Figure 16 box plots of free chlorine levels at the village scale

According to Figure 17 the median free chlorine values for all areas are < 0.2 mg/L. Most values are <0.4 mg/L expect for the outliers that up to 0.7 mg/L.

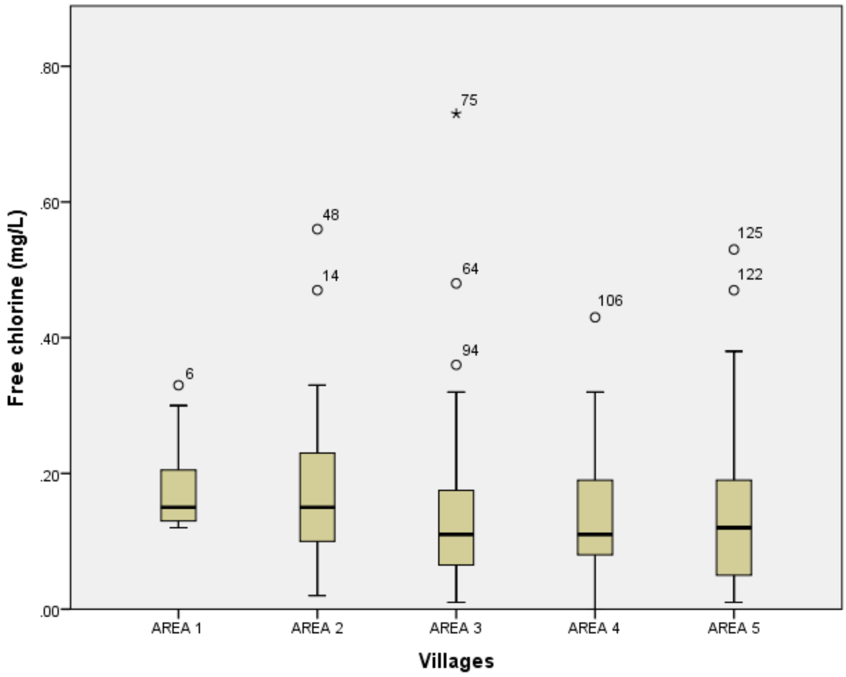

Figure 17 box plots of free chlorine levels at medium scale

The map shows that most of the samples have a chlorine residual below 0.2 mg/L. All the villages have samples with chlorine residual <0.2 mg/L. Nyakatooma and Bassajabalaba show to have the highest number of samples with a chlorine residual <0.2 mg/L. It is important to note that these samples were collected on different days and time.

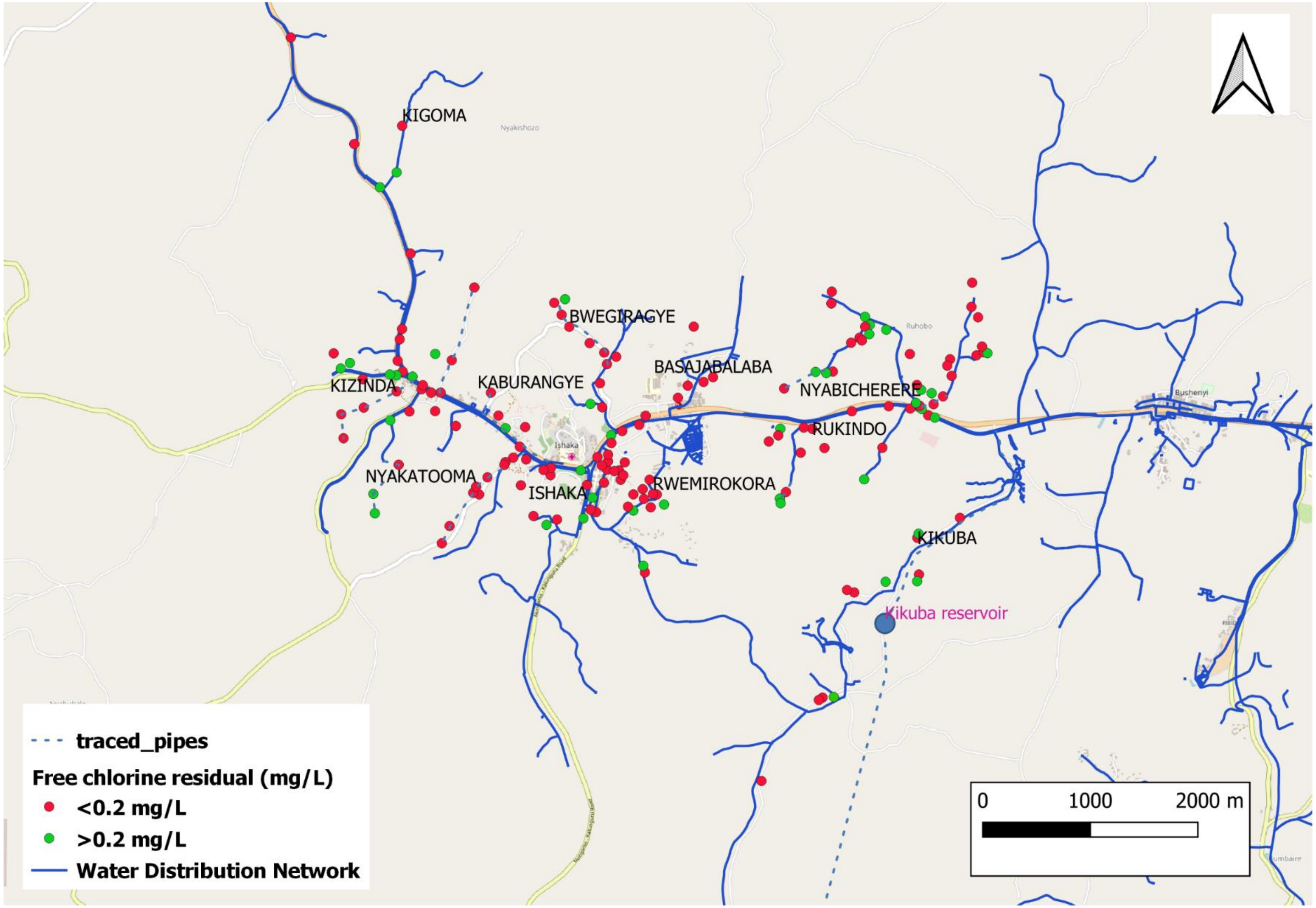

Figure 18 free chlorine residual per sampling point

Sanitary risk scores

The calculated sanitary risk scores per area of consideration were then classified to analyze the level of risk and the kind of actions that should be taken (see Table 5.1-7). A SIF scored for the entire area sampled had a sanitary score of 38. When the risk is classified, it falls under intermediate risk. This indicates that when resources are available, the WDN should be rehabilitated and other risks minimized.

Village scale

At the village scale, the highest score was 41 in Kizinda while the lowest was 15 in Rwemirokora. Most villages had a sanitary score of intermediate risk (21-40). Out of the twelve sanitary inspections carried out, ten had a score categorized as intermediate risk score, while one was categorized as high risk and one had a low risk score. See Table 5.1-7.

Table 5.1-7 Sanitary scores at village scale and its risk classification

Villages	Sanitary risk score	Risk classification
Bassajabalaba	29	Intermediate risk
Bwegiragye	23	Intermediate risk
Ishaka	32	Intermediate risk
Kabiriisi	26	Intermediate risk
Kaburangye	36	Intermediate risk
Kigoma	27	Intermediate risk
Kikuba	30	Intermediate risk
Kizinda	41	High risk
Nyabicherere	30	Intermediate risk
Nyakatooma	24	Intermediate risk
Rukindo	26	Intermediate risk
Rwemirokora	15	Low risk

Medium scale

The sanitary risk score for a combination of villages served by the same pipe main was considered at medium scale. All the sanitary inspections have a sanitary risk score classified under intermediate risk. The highest sanitary risk score is 37 while the lowest risk score is 25. See Table 5.1-8.

Table 5.1-8 Risk classification of sanitary risk scores at medium scale

Medium scale area	Villages represented	Risk score per area	Risk classification
AREA-1	Kikuba	30	Intermediate risk
AREA-2	Nyabicherere Rukindo	25	Intermediate risk
AREA-3	Bassajabalaba, Bwegiragye, Rwemirokora	30	Intermediate risk
AREA-4	Ishaka-Kabiriisi	29	Intermediate risk
AREA-5	Nyakatooma, Kaburangye, Kizinda, Kigoma	37	Intermediate risk

5.1.3 Hazards and hazardous events identified

Hazardous events that contribute to microbiological risks were identified in all the components of the WDN: the reservoir, transmission mains, washouts, gate valves, air valves secondary distribution pipes and the consumer taps. They were identified in line with the sanitary inspection checklist and then any other observed event that was likely to pose a risk to microbiological contamination was noted.

The reservoir

The water is pumped from the treatment plant to the reservoir through a 20 km pipeline. At the pumping station, a surge vessel is installed to avoid backflow of water into the clear well reservoir in case of power outage. This is a positive step towards avoiding recontamination. Unfortunately, the length of the transmission mains increases the residence time hence affects water age and leads to high chlorine consumption such that, by the time the water gets to the reservoir, residual chlorine is below national standards and WHO guideline value of 0.2 mg/L. The reservoir is divided into two compartments each with a separate inspection cover. The inspection cover of one compartment is always open (as shown in Figure 20) making the water at risk of contaminant intrusion during rains or flying birds. The compound where the tank is located is well fenced and protected from external contamination. The reservoir is made of precast concrete reinforced with aluminium bars; it has small cracks that allow water to leak through them (shown in Figure 19). The reservoir is scheduled to be cleaned once every three months. According to the operator, it was last cleaned in September 2018; throughout the study period, it was not cleaned. During the period of the burst on the transmission main, sediments and biofilm were observed at the bottom of the reservoir.

Figure 19 small cracks on the Kikuba reservoir walls

Figure 20 open inspection cover for the reservoir

As shown in Table 5.1-9, there were seven questions targeting risk factors at the reservoir. Generally, the reservoir was in good condition during the sanitary inspection. Four factors had no obvious hazards or hazardous events and thus no risk score, two were classified as low risk level, and one was considered to have a high probability of risk. The reservoir cover was in good condition; the fence around the reservoir was in excellent condition; there were no sources of pollution in the vicinity and no signs of contamination in the reservoir at a glance. However, there were small cracks on the reservoir walls which were classified as of low risk since there are low chances of contaminant intrusion. The inspection hatch for one compartment of the reservoir is left open throughout; there is a high probability of bird faeces falling into the reservoir which is direct exposure to faecal contamination hence classified as high risk. The inlet is at the top of the reservoir while the outlet is close to the bottom; there are low chances of short-circuiting.

Table 5.1-9 Reservoir checklist questions as they appear in the SIF

ID	Question as it appears on the SIF	Presence or absence of a risk		Risk level
1.	Is the reservoir open (i.e. uncovered), or if there is a cover, is it inadequate (e.g. cracked, damaged, leaking) to prevent contamination?	NO		
2.	Is the reservoir structure damaged, cracked or leaking?		YES	LOW
3.	Is there any point of entry (e.g. air vent, overflow pipe, inspection hatch cover) to the reservoir that is inadequately covered or sealed to prevent contamination from entering?		YES	HIGH
4.	Does the inside of the reservoir contain any visible signs of contamination (e.g. animal waste, sediment accumulation, scum, floating objects)?	NO		
5.	Can water short-circuit from the inlet to outlet?		YES	LOW
6.	Is the fencing or barrier around the reservoir absent or inadequate to prevent contamination or unauthorized entry?	NO		
7.	Can signs of sources of pollution be seen within 10 meters of the reservoir (e.g. latrines, animals, rubbish, and open defecation)?	NO		

Transmission Mains

The transmission mains from the reservoir are primarily ductile iron pipes. The pipes are laid through human-made forests and swamps where animals graze. At some places, the pipes are left exposed due to the ground condition or due to erosion. This is hazardous to the water especially at the joints; faecal contamination can easily intrude in times of low pressures. The pipes are also at risk of being broken during human activities or accidentally stepped on by animals. At one point, the exposed pipe was observed submerged in a puddle of water (as shown in Figure 22, and there were animals grazing within 10 m proximity. A T-junction that divides water to Bushenyi-Ishaka, and Kikuba-Ruharo is also left open after repair (as shown in Figure 21), during rainy season water can easily fill up allowing contaminant intrusion through the joints. In Bassajabalaba, the main that supplies Ishaka market, Kizinda, and Bwegiragye, passes through the swamp. It is laid on small piers which have failed with time and are submerged into the swamp as shown in

Figure 23.

Solid waste dumping was observed and noted where there was exposed pipes. For example, there was visible solid waste dumping on this swamp and flow of wastewater from a nearby car wash where the pipe was exposed and submerged into the swamp.

Figure 21 ponding water in the swamp, joint left uncovered after repair

Figure 22 T-junction left uncovered after repair

Figure 23 transmission main submerged in the swamp

Secondary mains

The secondary mains connect the transmission mains to the consumer outlets. Some were found exposed due to erosion (Figure 25) while others were left uncovered during construction or repair. Four pipes were found leaking, due to cutting during laying of new pipe extensions, bursts due to pressure transients and some in hidden places due to unknown reasons (as shown in Figure 28. The water is highly at risk of contamination during low pressures and also during repair, contaminants can easily intrude into the pipes. There were no obvious illegal connections along the pipelines, thus no risk scores for the said risk factor.

Apart from the risks based on the sanitary risks checklist, there were many others observed. Along the mains, there was a lot of solid waste dumping, and some exposed pipes were found near a trench for grey water. The secondary main supplying Kikuba village passes through the solid waste dumping site. During the rainy season, the water is at risk of microbial contamination. Some exposed pipes were found in stormwater and greywater drainages which are dirty and soaked in solid waste (as seen in Figure 26, Figure 24). These pipes are at risk of physical breakage, and the contaminants can easily intrude through the joints in times of low pressure in the pipe network. During the transect walks, uncapped pipes were seen left unused near the trenches. Leaving pipes uncapped at the ends makes them vulnerable to foreign matter getting into the pipe. The pipes stored in the pipe yard are also left uncapped as seen in Figure 5.

Figure 24 a pipe soaked in stagnant storm water

Figure 25 jointed pipes exposed due to erosion

Figure 26 jointed pipes exposed and passing through the stormwater drainage

Figure 28 leaking pipes in a hidden place

Figure 27 unused pipe left on site

Figure 29 unused pipes left on site and animals grazing close by

Lack of water at the tap stands

As mentioned earlier, sampling points were selected during the transect walk surveys; however, during sampling, some taps did not have any water at the tap while the neighboring taps had water. For example, during the transect walks in Nyakatooma village, an exposed pipe was noted, it served one tap that served many households. This tap was of interest and thus one among the selected sampling points for Nyakatooma. During sampling, it was found to have no water.

Valves

The recently installed washouts and air valves on the mains from Kikuba reservoir to the T-junction are still in good condition. They are well covered and clean. The valves on the mains in Ishaka, Bassajabalaba and Kizinda are old, dirty and uncovered putting the water at risk of microbiological contamination. The valve seen in Bassajabalaba is near the KIU referral hospital and the stormwater in the hospital compound flows into the open valve chamber and there is also solid waste strewn in it and around it. See figure below

Figure 30 unsanitary valve chambers in Ishaka and Bassajabalaba

Tap stands

Tap stands in Ishaka are generally not fenced. However, there is a lock installed on the tap to avoid illegal consumption and vandalism of the meters and tap heads. 69% of the taps have concrete floors while the rest does not. Individuals in the villages place bricks, blocks or stones around the tap such that they act as a concrete floor. Half of the taps have poor drainage or lack drainage channel; hence water accumulates when it pours. Some tap stands (7.2%) had animals like dogs, goats, and chicken within 10 m proximity. 9% had rubbish close by, while others were very close to a latrine (12%) despite being used for fetching drinking water (see Figure 31).

Apart from the risk factors provided by the sanitary inspection checklist, other risks were observed around the tap stands. Some other taps were located very close to a septic tank while others were located close to greywater trenches. Among the households, it was noted that most of the families owned a utensil rack and placed it close to the tap stand. The hazardous events are shown in Figure 31. According to many tap owners, there are barely any maintenance activities carried out towards the tap stands; a few people slash grass around the tap stand, others clean the concrete floor if present while others sweep around the tap stand. During sampling, one tap was found to be leaking while three meters were also found leaking.

a) a tap stand within 10 m proximity of the latrine

b) a tap stand with blocks at the floor

c) a tap stand built close to the grey water trench.

d) a tap stand with animals within 10 m proximity

Figure 31 hazardous events observed around the tap stand

Table 5.1-10 showing the hazards and hazardous events observed around the taps

Tap stands (N=169)	**Occurrence**
Dirty or damaged attachments on the tap stands	1.8% (3/169)
Poor drainage	50% (84/169)
The absence of concrete floor around the tap stand	69% (116/169)
Absent or inadequate fencing or barrier around the tap stands	100% (169/169)
Signs of sources of pollution within 10m vicinity i.e. latrine	12% (21/169)
Signs of sources of pollution within 10m vicinity i.e. rubbish	9% (15/169)
Signs of sources of pollution within 10m vicinity i.e. animals	7.2% (12/169)

5.1.4 Risks identified in the WDN of Bushenyi-Ishaka municipality

The Table 5.1-11 shows a summary of the hazards and hazardous events observed and the associated microbial risks in the WDN during this study

Table 5.1-11 actual and potential risks identified in the water distribution network

Integrity breached	**Specific event/ situation that can occur**	**Part of the network affected**
Physical integrity	Small cracks were observed on the walls of the reservoir. These could allow intrusion of contamination in times of low pressure,	reservoir
Water quality integrity	The reservoir had exceeded routine cleaning. When there was no water, sediments and bio-growth were observed at the bottom.	
Physical integrity	During and after repairs there was backflow into the pipe due to disturbance of the surrounding leading to increased turbidity and possible pathogen intrusion.	Backflow into the system
Water quality integrity	Due to the distance between the treatment plant and the reservoir, there is high chlorine consumption and decay along the way. The chlorine residual in the reservoir and at the tap stands was too low.	Secondary disinfection
Physical integrity	The pressure in the system is imbalanced, the places with low pressures experience ingress of contaminants into the system. Flushing of the system is rarely done which leads to accumulation of biofilms, sediments and particles in water mains due to low flow velocities in pipes and resuspension during high-flow events.	System operations
Physical integrity	Contamination of distribution system during new installations, including water meter, valve or laying of new pipes. debris, soil or groundwater remaining in the main after repairs and not removed during the main recharge operation Damage of existing pipes when laying new pipe extensions, can lead to possible contaminant intrusion.	System construction and repair
Water quality	After repair of the burst on the transmission main, most of the samples collected tested positive for *E. coli*.	
Physical integrity	Some taps were very unsanitary with rubbish dumped nearby, others with a latrine in a 10m proximity, others with poor drainage, and with animals close by this led to Increased exposure to contaminants.	Tap stands
Hydraulic integrity	Leaking taps and meters, leakage decreases the pressure in the pipe thus can allow contaminant intrusion.	
Water quality	Lack of maintenance and cleaning of the overhead tanks, deteriorates water quality	

5.1.5 Risk factors and *E. coli* concentration

According to Table 5.1-12, all the 169 (tap stands) sampling points did not have a fence or barrier around them. There were only three sampling points with damaged or unclean attachments, and all had faecal contamination. Ninety-five tap stands had poor drainage, but only 50 (53%) had faecal contamination. One hundred twenty-three tap stands had inadequate or no concrete floor around them, and 68 (55%) had faecal contamination. Most of the tap stands with signs of pollution within 10m range were very likely to have faecal contamination. 76% of the tap stands with a latrine in the vicinity had a positive indication of faecal contamination. 73% of the tap stands with animals within 10m radius had a positive indication of faecal contamination while 75% the tap stands with rubbish close by had a positive indication of faecal contamination.

Table 5.1-12 showing risk factors and sampling points with a positive indication of faecal contamination

Risk factor	**Total number of sampling points that were affected by a particular risk factor**	**Number of samples positive to faecal contamination**	**% of the number of samples positive to faecal contamination.**
Presence of damaged or unclean attachment	3	3	100
Poor drainage	95	50	53
Absent or inadequate concrete floor	123	68	55
Absent or inadequate fence/barrier	169	95	56
Latrines within 10 m	21	16	76
Animals within 10 m	15	11	73
Rubbish within 10 m	12	9	75

According to the map below, the risks observed along the distribution network does not have much association with the *E. coli* concentration. Generally, there are more hazards and hazardous events identified in shopping centres compared to more rural settings. In Kaburangye there were many risks observed; exposed pipes, poor drainage at the tap stand and signs of erosion but there was no observed *E. coli* concentration. On the contrary In Bwegiragye, there were very few risks observed but all the samples had *E. coli* concentration.

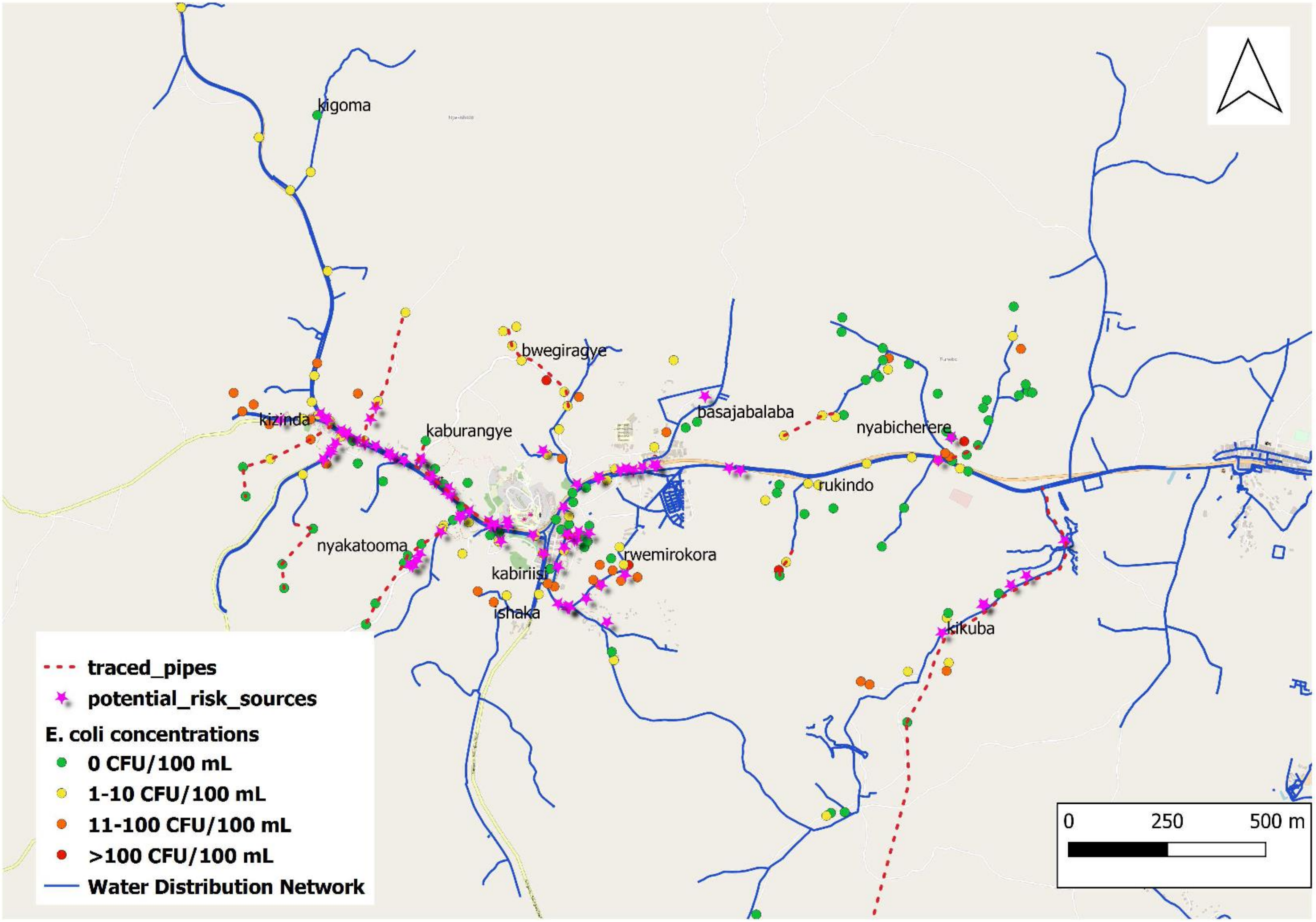

Figure 32 a map showing identified risk points along the water distribution network

5.1.6 Risk evaluation and prioritization

For risk analysis, the results of *E. coli* concentration and sanitary inspections were combined in a risk matrix. The examination of *E. coli* concentration together with the sanitary risk scores made it possible to prioritize the areas that require urgent attention. This is important to be able to recommend control measures.

The examination at village scale as shown in Table 5.1-13 resulted to, many samples were categorized to be under intermediate risk with the number of risk scores ranging from 21 to 40 sanitary risk scores and *E. coli* concentrations between 0-100 CFU/100 mL. Some samples from Rwemirokora village were classified under low risk with a sanitary risk score of 15 while samples in Kizinda village were classified under high risk. This indicates that Kizinda requires urgent attention and that a control measure should be recommended. Comparing these results to Figure 9, all samples collected from most of the secondary distribution pipes in Kizinda, showed to be contaminated. Therefore, urgent flushing of the distribution network in Kizinda is recommended.

Table 5.1-13 risk levels calculated from both sanitary risk scores and *E. coli* concentration at village scale

		Sanitary risk scores		
		1-20 Low risk	**21-40 Intermediate risk**	**41-65 High risk**
***E. coli* concentration (CFU/100 mL)**	**0**	2	69	7
	0.5-10	3	43	11
	11-100	6	17	10
	>100	1	4	0

As shown in Table 5.1-14, A Kruskal Wallis test was used to compare the median values of *E. coli* concentrations based on risk classification at the village scale. The median of *E. coli* concentrations in the low risk classification had a median of 13.5 CFU/100 mL while in intermediate risk classification the median was 0 CFU/100 mL. There is therefore a significant difference as the p. value is < 0.05.

Table 5.1-14 Kruskal-Wallis test used to compare the median value for *E. coli* concentrations in each risk category at village scale

	low risk	**intermediate risk**	**high risk**	
median	13.5	0	6	
rank sum	1387	10121	2857	
count	12	129	28	169
r^2/n	160314.0833	794066.9845	291516.0357	1245897.104
H-stat				10.38862661
H-ties				11.34965965
df				2
p-value				0.003431253
alpha				0.05
sig				yes

At medium scale as shown in Table 5.1-15, when the sanitary risk scores and *E. coli* concentration at medium scale are combined in a risk matrix, the WDN is classified to be under intermediate risk level. On the other hand, when the sanitary risk scores (38) and *E. coli* concentration at large scale are combined in a risk matrix, the WDN is classified to be under intermediate risk level. Intermediate level of risk indicates that when there is availability of resources, the distribution network should be given close attention.

Table 5.1-15 risk levels calculated from both sanitary risk scores and *E. coli* concentration at medium scale

		Sanitary risk scores		
		1-20 Low risk	**21-40 Intermediate risk**	**41-65 High risk**
***E. coli* concentration (CFU/100 mL)**	**0**	0	74	0
	0.5-10	0	52	0
	11-100	0	38	0
	>100	0	5	0

Generally, when the classification is carried out at the village scale, the samples are well distributed in the table showing that the risk levels differ in different villages within the WDN. However, the most significant number of samples were classified under intermediate risk level. The distribution of samples when classified at medium scale and large scale is the same; all samples fall under intermediate risk classification. When the sanitary inspections are applied at a smaller scale, they capture better local risks.

5.2 Statistical correlation between sanitary risk scores and water quality data

5.2.1 Statistical correlation between sanitary risk scores and *E. coli* concentration at the village scale

According to Table 5.2-1, there is no statistically significant correlation between *E. coli* concentration and sanitary risk scores at the village scale (Spearman's rho = 0.055, p = 0.474).

Table 5.2-1 Spearman's correlation between *E. coli* concentration and sanitary risk scores at village scale

			Risk scores at village scale
Spearman's rho	***E. coli* count CFU/100 mL**	Correlation coefficient	.055
		Sig (2-tailed)	.474
		N	169

A scatter plot is used to visualize the relationship between *E. coli* concentration and sanitary risk scores, as shown in Figure 33. The r-squared value is about 0.05 which is very close to zero. This shows that there is a very weak uphill relationship between *E. coli* concentration and sanitary risk scores. Comparing the results of spearman's correlation and scatter plot, the positive correlation coefficient observed may be due to chance considering there is no significant relationship between the two.

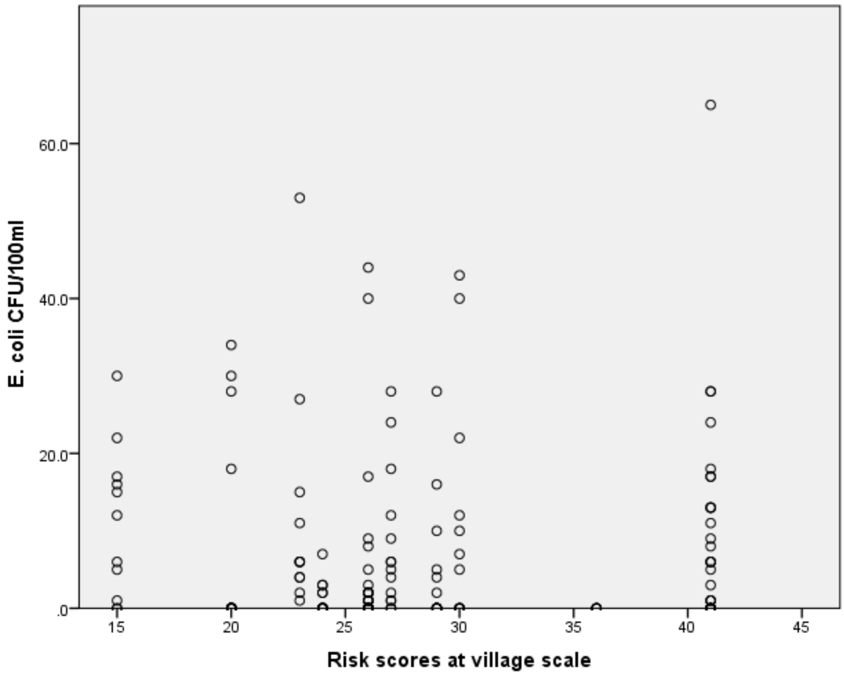

Figure 33 a scatter plot showing the correlation between *E. coli* concentration and sanitary risk scores at the village scale

5.2.2 Statistical correlation between sanitary risk scores and *E. coli* concentration at medium scale

According to the table below, the correlation coefficient between *E. coli* concentration and sanitary risk scores at medium scale is 0.093. However, the P-value is greater than 0.05, thus the relationship observed is not statistically significant. However, it is notable that the correlation coefficient at large scale is slightly greater than correlation coefficient at the the village scale.

Table 5.2-2 showing spearman's correlation between *E. coli* concentration and sanitary risk scores at the village scale

			Risk scores at medium scale
Spearman's rho	***E. coli* count CFU/100 mL**	Correlation coefficient	.093
		Sig (2-tailed)	.231
		N	169

A scatter plot is used to visualize the relationship between *E. coli* in and sanitary risk scores as shown in Figure 34. The linear r-squared value is about 0.00057 while the quadratic r-squared is 0.027 which are both very close to zero. These findings align with the positive coefficient observed in the Spearman's ranking shown above. However, it is evident that the R-squared for correlation at village scale is greater than at medium scale.

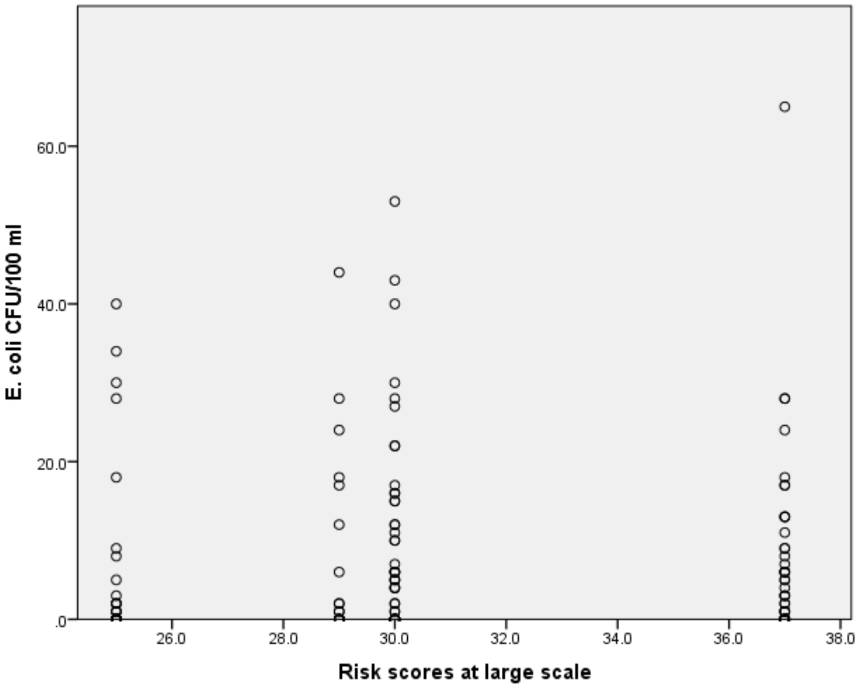

Figure 34 a scatter plot showing the correlation between *E. coli* concentration and sanitary risk scores at large scale

5.3 Determining the predictive value of sanitary inspections (village scale)

5.3.1 Determination of the predictive value of sanitary inspection based on sanitary risk score at the village scale

According to Table 5.3-1, the positive predictive value of the observed sanitary risk scores to the *E. coli* concentration measured is 89.5% while its negative predictive value is at 2.7%. The sensitivity and the specificity are calculated as 54.1% and 16.7%, respectively.

Table 5.3-1 predictive value of sanitary inspections at the village scale

Observed		**Predicted**		
		Status		**Percentage Correct**
		0	**1**	
Status	**0**	2	72	2.7
	1	10	85	89.5
Overall Percentage				**51.5**

The null hypothesis where the sanitary risk score is not in play, estimates a 56% of samples with *E. coli* presence. However the sanitary risk score predicts that 51.5% of the samples are correctly predicted. A Recipient operating characteristic (ROC) curve was plotted (true positive rate against false positive rate) to check the accuracy of sanitary risk scores at predicting microbiological contamination. The accuracy of prediction is measured by the area under the ROC curve (AUC). The higher the AUC the higher the ability of sanitary inspections to predict positives as positives and negatives as negatives. According to Figure 35 the AUC is 0.547 which indicates that there is 54.7% chance that the *E. coli* concentrations are accurately predicted by sanitary inspections.

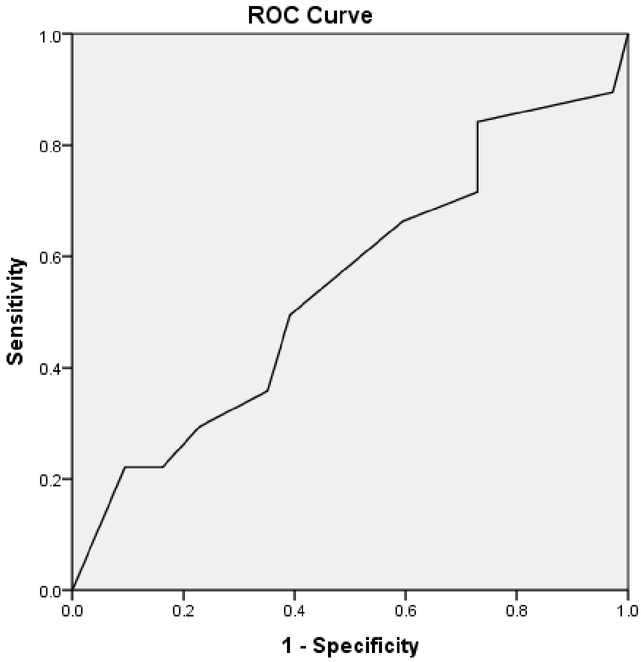

Figure 35 ROC curve showing predictive value at the village scale

5.3.2 Determination of the predictive value of sanitary inspection based on sanitary risk score at medium scale

According to Table 5.3-2, the positive predictive value of the observed sanitary risk scores to the *E. coli* concentration measured is 82.1% while the negative predictive value is at 35.5%. The calculated sensitivity is 61.9% while the true negative rate is 60.5%.

Table 5.3-2 showing the predictive value of sanitary inspections at large scale

Observed		**Predicted**		
		Status		**Percentage Correct**
		0	**1**	
Status	**0**	26	48	35.5
	1	17	78	82.1
Overall Percentage				**61.5**

The null hypothesis where the sanitary risk score is not in play, estimates a 56% of samples with *E. coli* presence, however the sanitary risk score predicts that 51.5% of the samples are positive. A (ROC) curve was plotted to check the accuracy of sanitary risk scores at predicting microbiological contamination. According to Figure 35 the AUC is 0.573 which indicates that there is a 57.3% chance that sanitary inspections can be able to distinguish between the positive indication of faecal contamination and negative faecal contamination.

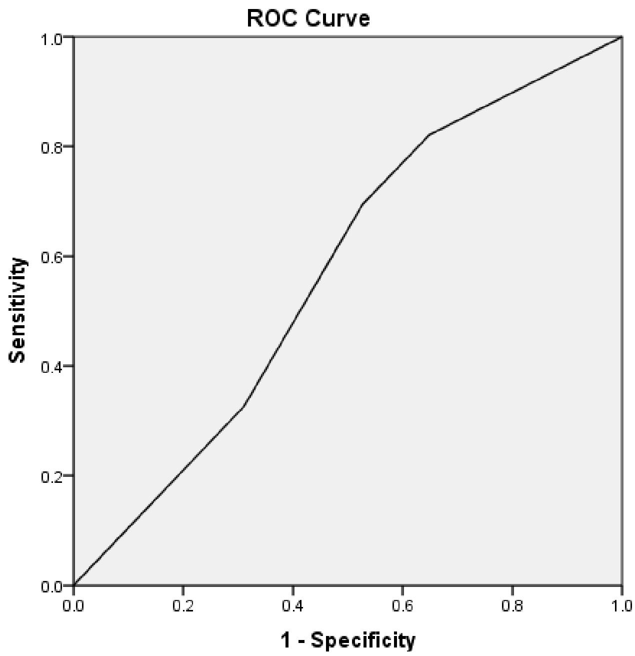

Figure 36 ROC curve showing predictive value at large scale

From the above analysis, it is evident that the sanitary inspections for piped distribution have poor ability to predict presence or absence of *E. coli* concentrations in the water.

5.4 Discussion

The discussion starts with a general considerations on the water quality supplied by Bushenyi-Ishaka municipality. In response to the first objective, the discussion touches on the risks identified in the distribution network. This is based on results obtained through the risk factors assessed according to the SIF checklist and the general observations made during the transect walks. The research objective one builds up to show the highly ranked risks through a risk matrix based on the risk classifications of both *E. coli* concentration and sanitary risk scores. To tackle objective two, the discussion focuses on the findings of the statistical correlation between sanitary risk scores and the *E. coli* concentration. Subsequently, the discussion looks at the ability of the sanitary risk scores to predict the presence of *E. coli* concentration in water. To conclude, based on observations of sanitary inspection application at small scale and at large scale, the most appropriate scale of application is selected.

5.4.1 Drinking water quality

Although Bushenyi water supply is an improved source of drinking water, it is likely to provide unsafe water to its consumers. About 56% of the samples showed a positive indication of *E. coli* presence. There were no *E. coli* found in the reservoir in most of the samples collected. However, there was one sample with 6 CFU/100 mL collected on 16th January 2019. The samples collected on the same day from the distribution network had *E. coli* concentration varying between (0-4) CFU/100mL. This contamination could be attributed to external contamination through the inspection hatch into the water. Among the SIF checklist questions, inadequately covered entry points into the reservoir (such as the inspection hatch cover, air vent, and overflow pipe) are considered as risk factors. In the course of this study, during sampling at the reservoir, it was observed that the inspection hatch cover was always open. It was thus classified at high risk because in case of birds dropping, they would go direct into the water, increasing chances of contamination.

During the treatment process, chlorine is dosed twice: during pre-chlorination 1 mg/L of chlorine is added mainly to protect the operation of the plant (by controlling odour and algae problems) while 5 mg/L of chlorine is added during disinfection. Nonetheless, the chlorine residual at the reservoir was as low as 0.1 mg/L (see Table 5.1-1). This can be attributed to high chlorine consumption due to the distance between the treatment plant and the reservoir. The presence of protective levels of chlorine residual in the distribution system is intended to protect the water from microbiological re-contamination, reduce bacterial re-growth and biofilm formation, and to serve as an indicator of the distribution system integrity (VanBriesen, et al., 2011). However, if the chlorine residual is low at the reservoir, then the residual chlorine that reaches the distribution network is too low to protect the water from recontamination. The chlorine residual at Kikuba reservoir was low ranging between 0.1-0.5 mg/L before booster chlorination was implemented. Low chlorine residual could be another possible explanation for the contamination detected in the reservoir.

High chlorine demand can also be attributed to possible presence of organics in the water which reacts with chlorine to form the formation of trihalomethanes. According to experiments carried out by Fang Yee, (2019), on dissolved organic matter and its impact on chlorine demand, it was observed that the water samples with higher dissolved organic matter concentration have a higher chlorine demand. However, trihalomethanes or any other disinfection by-products is not measured in Bushenyi-Ishaka water supply system.

Recently, a control measure was applied to curb this problem; booster chlorination was initiated at the reservoir to increase the residual chlorine at the reservoir and hence increase the chlorine residual at the consumer outlets. The chlorine boost has led to an increase in residual chlorine at the reservoir to about 1 mg/L leading to a consequential increase in the residual chlorine in the distribution network from an average of 0.12 to 0.18 mg/L. Despite chlorine booster at the reservoir, the chlorine residual is still below the minimum recommended chlorine residual at the taps of 0.2 mg/L.

According to the WHO (2017), the optimum pH for drinking water systems will vary between 6.5-9.5 depending on the composition of water and the nature of the construction materials used in the distribution system. pH has no direct effect on the consumers' health, but it is a crucial operational parameter. For effective disinfection, pH should be maintained below 8. The pH of the water entering the distribution system must also be controlled to minimize the corrosion of water mains and pipes in household water systems. Corroded pipes promote biofilm growth. The water provided from Nyaruzinga treatment plant had an average pH of 4.5 which was highly acidic. Raw water from Nyaruzinga wetlands was reported to be high in organics which came in the way of pH correction. With low pH the iron in the raw water from Nyaruzinga wetlands remained in a soluble state, this led to the supply of brown water to the consumers. On the contrary, the samples obtained during this study from Kitagata supply system, the pH range of 5.5-7.4 with a median of 6.7.

The turbidity level has improved after installation of Kitagata treatment plant compared to that of Nyaruzinga treatment plant (Twesigye, 2018). The results of this study showed a median value of 2 NTU compared to 5 NTU obtained in the previous study. Nyaruzinga, water treatment plant, has been in use since 1999 and was last rehabilitated in 2008 (Twesigye, 2018). The treatment infrastructure is thus old and deteriorated and has low efficiency in treatment operations. This can be another explanation for the high turbidity in water supplied from Nyaruzinga treatment plant compared to water supplied from Kitagata treatment plant.

Additionally, turbidity levels vary greatly depending on the sampling point and the conditions of the day of sampling. For example, in case of a leakage that is unidentified, the pressure in the pipe network drops allowing backflow and debris intrusion at the points of weakness in the pipe system leading to turbid water at the consumer outlet. Also, the vulnerability of the distribution network to recontamination differs within the system due to the different conditions related to the particular part of the network. Therefore, apart from a few variations which can be attributed to many reasons, it is safe to say that water provided by Bushenyi water supply has turbidity levels <5 NTU, which is recommended by the WHO.

According to the scoping study, Bwegiragye was among villages affected by intermittent lack of supply. Also it had *E. coli* in all the samples collected during this study. Bwegiragye is located in an elevated area; thus the primary cause of lack of supply could be low pressures in the distribution network. When the pressure in the pipe is lower than the pressure in the surrounding environment, faecal contamination may enter into the pipe. Also during times of no supply, there is biofilm growth in the pipe and growth of microorganisms fuelled by low chlorine residual in the network. This has been generalized for many water supplies in low-income countries and rural areas. A metric study carried out on faecal contamination in low and middle income countries showed that about a quarter of samples collected from improved water sources contained faecal contamination (Bain, et al., 2014).

According to the scoping study at the beginning of the study, Ishaka and Kigoma villages were mentioned to have poor water quality, compared to the findings of this study, 88% of samples collected in Ishaka and 83% of samples collected in Kigoma had *E. coli* concentrations. The findings, therefore, agree with the scoping study.

Generally, the results of this study show that after treatment, the water quality changes negatively and steadily through transmission and distribution to the consumer outlet this confirms the findings of Bain (2014). The *E. coli* concentrations varied greatly among the samples; this could be attributed to the fact that samples were collected on different days and can be pinned to seasonal variations such as rainfall. pH levels increased progressively throughout the sampling period. This can be attributed to the recently connected Kitagata treatment plant where the operators are still working on obtaining an optimum pH correction, and this goes too for the variation in chlorine residual.

5.4.2 Identified hazards and hazardous events

During this study, many potential and actual hazards and hazardous events in the water distribution network up to the consumer outlets that are likely to cause microbiological contamination were identified. These include: the inspection cover of the reservoir always left open, bursts and leakages on the pipes, pipe exposure due to erosion, presence of signs of pollution within 10 m of the tap stands, poor drainage around the tap stands, absent or inadequate concrete floors around the tap stands and absence or inadequate fence or barrier around the tap stand. Apart from the risk factors listed in the sanitary inspection checklist, other risk factors were identified. These include low chlorine levels in the distribution network, low pressures in the network, tap stands located close to the grey water trenches, jointed pipes laid in the stormwater drainages, possible cross-contamination between a septic tank and drinking water outlets, and clothes washing at the tap stands. Low chlorine residual and low pressures in the network were observed during water quality analysis.

5.4.3 The relationship between risk factors and the *E. coli* presence

Among the risk factors identified around the tap stands, the presence of signs of pollution within 10 m proximity had the highest probability of causing contamination. 76% of the tap stands with a latrine within a 10 m radius showed the presence of *E. coli*. Additionally, recent research carried out on sanitation in Bushenyi showed that traditional pit latrines are commonly used in Bushenyi and they are not emptied. When they are full, they are covered, and a new one is dug and constructed. This study mentioned that during the rainy season, there is possible seepage from the latrines (Nyakutsikwa, 2018). There is, therefore, a high probability of intrusion when the pressure in the drinking water pipe is lower than the pressure in the surrounding environment. These findings are in contrary to a study carried out in Bangladesh on tube wells that showed that neither presence of a latrine or an improved latrine in the compound nor child defecation and faeces disposal practices were associated with tube well water quality (Snoad, et al., 2017).

Generally, many factors should be considered for there to be an association between the presence of a latrine and contamination of drinking water at the tap stand. These include contaminant transport distance, rainfall, type of soil and possibility of filtration in the soil, and also the water source type (O'Dwyer, et al., 2018). The average depth of pit latrines in Bushenyi is 1.8 m while the average depth of a water service pipe is 0.5 m. There are therefore higher chances of contamination of piped water compared to wells that have a depth of up to 50 m. Due to these factors, it is difficult to justify the association between *E. coli* concentration in the water and the presence of a latrine in the proximity.

Additionally, it was observed that tap stands in the villages are not fenced. However, it was noted that all tap stand owners had a lock to avoid unauthorized consumption. 56% of the samples collected were contaminated. Fencing around the tap stand does not seem to an influence on the presence or absence of faecal contamination in piped distribution. Based on the fact that all the sampling points were not fenced, it is difficult to tell if there was any association between the fence around the tap stand and *E. coli* presence in water.

Generally, there were no apparent signs of illegal connections in the distribution network. Nonetheless, illegal connections to the water distribution network endanger the safety of the water through possible contamination. During the scoping study, it was mentioned that due to the vigilance of the NWSC staff, water theft and illegal connections has significantly reduced with time. For the applicability of this risk factor, a better method of identifying illegal connections should be developed in line with the SIF.

Among the risks identified in the general water distribution network and its surroundings, pathways for pathogen intrusion such as leaks, bursts and low pressures in the distribution network have a higher probability of risk compared to risks like exposed pipes and signs of erosion. Low pressure in the network is a big driver for contaminant intrusion and backflow, according to a study carried out on contaminant intrusion by Besner (2011). Low pressures in the network have the potential to result in contaminant intrusion from external sources. Also in the course of this study, there were two significant bursts which led to a lack of supply for about two weeks. The samples collected on the 2nd of February 2019 after repair of the bursts showed high contamination after a lack of supply for about two weeks. This was despite the chlorine boost at the reservoir; this agrees with the research carried out by Kumpel et al. (2014) on the mechanisms affecting water quality in intermittent water supply. Kumpel et al. (2014) found that at low pressures elevated indicator bacteria were frequently detected even when there was a chlorine residual, suggesting persistent contamination had occurred through intrusion or backflow. Also, according to Bain et al. (2014), intermittency and inadequate chlorination can be generalized as leading risk factors for microbial contamination of piped supplies.

The leading causes of the risks identified are design or construction deficiencies, poor operation and maintenance, and structural deterioration with time. According to the interviews with the NWSC staff, it was mentioned that the pressure, elevations and ground levels are surveyed when the water does not reach the intended outlets. This leads to imbalanced pressures in the network. Bushenyi district has a generally hilly terrain. During this study, it was evident that the water pressure in the high areas was low and sometimes there was no water at the tap outlet. It was evident that hilly areas suffer intermittent supply which increases the microbiological risk in the WDN. According to the technical manager, there is routine maintenance to flush the system once every two months; however, this is not well complied with. Instead, flushing is done in case of complaints from the consumers about the quality of water they are receiving and also after repairs. The poor water quality in the distribution network especially in Kizinda can be attributed to lagging in flushing routine.

Bushenyi-Ishaka WDN also suffers structural deterioration. It has been in operation for so many years. However, it was taken over by NWSC from water development under the ministry of water and environment. There exist some asbestos cement water mains that are very old and highly prone to burst and probably worn out inside thus can hide pathogens and encourage biofilm growth. The valve chambers have also been neglected and old thus highly prone to pathogen intrusion and growth. Also, according to an assessment carried out on Bushenyi-Ishaka water supply system by (Twesigye, 2018), old asbestos cement pipes are the main cause of bursts in the distribution network. These findings are in accordance with a recent study carried out in the USA on drinking water and public health in an era of aging distribution infrastructure. This study by Allen (2018) states that, old infrastructure does not only disrupt the citizens but is likely to pose increased health risk.

5.4.4 Prioritization of risks

The level of risk for samples collected varied substantially based on the severity of consequence and the likelihood of occurrence. Generally, 53% of the samples ranged between low (1-10 CFU/100 mL) and intermediate risk level (11-100 CFU/100 mL) based on *E. coli* concentration. When the risk level classification was considered at village scale, there was variability in the results. The highest sanitary risk scores were in Kizinda (41) which falls under high risk level of classification. According to Bartram (1991), this level of risk should be highly prioritized and requires urgent action. Rwemirokora had the lowest sanitary risk score (15) falls under a low level of risk classification and therefore should be given low priority. At a medium scale, AREA 5 which is a combination of Nyakatooma, Kaburangye, Kizinda, and Kigoma has the highest sanitary risk score of 37 while area 2 has the lowest sanitary risk score of 25. However, all the samples fall under intermediate scale compared to the variability at the village scale. At a large scale, the sanitary risk score was 38, which falls under the intermediate risk level of classification. According to Bartram (1991), this indicates that the water distribution network should be given priority of improvement when there is the availability of resources.

Generally, it is logical that the higher the number of the sanitary risk score, the greater the *E. coli* concentration and hence the higher the probability that the consumers will receive poor quality water. However, this was not the case for many villages in Bushenyi-Ishaka municipality. According to Table 5.1-13, Rwemirokora village has 83% of samples with *E. coli* concentration but has a sanitary risk score of 15 while Kaburangye village shows no *E. coli* concentration among all the samples but has a sanitary risk score of 36. This can be attributed to the fact that a single water sample is representative of the moment in time when that sample is taken and changing environmental conditions, particularly rainfall, may rapidly alter the degree of contamination of a poorly protected distribution network (WHO, 1997). On the other hand, Rwemirokora shows the lowest sanitary risk score but has the highest median for *E. coli* concentrations at village scale. According to (WHO, 1997), a low sanitary risk score with high faecal contamination still requires urgent action. Therefore, this coupled with the lack of water supply when other villages have water, should be investigated further and a control measure applied.

5.4.5 Statistical correlation between sanitary risk scores and E. coli concentrations

Generally, there is no significant statistical correlation between *E. coli* concentration and the sanitary risk scores. These results are consistent with other studies carried out in developing countries. A study carried out in Kisii Kenya, on different sources of drinking water, showed that there is no association between TTC and the overall sanitary risk scores (Misati, et al., 2017). Another study carried out on tube wells in flood-prone areas in Bangladesh showed that there was no significant association between tube well contamination with *E. coli*, TTC or TC (Luby, et al., 2008). Similarly, Parker et al., (2010) suggest that while there was a significant correlation between TTC and sanitary score, this correlation was weak and 71% of the variation in TTC cannot be explained by variation in the sanitary risk score.

Generally, the correlation was instead more related to the specific risk factors. The sampling points with signs of pollution within 10 m were highly at risk of faecal contamination compared to those with poor drainage and inadequate or absent concrete floor. This is a clear indication that SIFs cannot be used in place of microbiological water quality monitoring.

5.4.6 The ability of sanitary inspections to predict E. coli presence or absence in the WDN

The predictive value was calculated using binary logistic regression and its accuracy was checked using the AUC under the ROC curve. This was important because according to (Snoad, et al., 2017), the presence of a statistical correlation does not guarantee the ability of the sanitary inspections to discriminate between the presence or absence of *E. coli* concentrations. The predictive value at village scale (54.7%) is slightly lower than the predictive value at medium scale (57.3%). The predictive value at large scale is equal to the null hypothesis (56%). Conclusively sanitary inspections for piped distribution have a very low ability to predict the presence of *E. coli* in piped distribution. These findings were in agreement with those of (Snoad, et al., 2017) on the effectiveness of sanitary inspections as a risk assessment tool for thermo-tolerant coliform bacteria contamination of rural drinking water, in India. They stated that sanitary inspections have poor ability to discriminate between presence and absence of *E. coli* concentrations.

Another study carried out in Bangladesh on the ability of sanitary inspections to predict risk of microbiological contamination in ground water sources showed that the positive predictive value for *E. coli* concentrations was < 50%. This is on the contrary of the findings of this research where the positive predictive value was > 80% for both village scale and medium scale. However the negative predictive value was very low at village scale (2.7%). For there to exist a good predictive ability, both the positive predictive value and the negative predictive value should be high. Therefore, the accuracy of the sanitary inspections at predicting the presence of *E. coli* concentrations was poor.

It is worth noting that this study was based on piped water distribution network while the studies in comparison are mostly based on studies carried out on groundwater (tube wells, boreholes). The previous studies used the number of risk factors on the checklist as the total number of sanitary risk scores. This differs with the sanitary inspection for piped distribution used in this study that has a quantitative risk matrix to calculate the risk scores with a maximum of 65.

Also, the water quality analysis is representative of the quality at that particular time, whereas the sanitary inspection considers previous history of the water distribution network and the potential future points of risk. Therefore despite the incomparable results, the identified risks should be put into consideration.

5.4.7 Limitations of the study

There were difficulties in locating some of the pipes on the ground according to the AUTOCAD file provided.

Bushenyi Ishaka WDN is not zoned, there are therefore no physical demarcations to show the boundary around each village it was therefore not easy to pin the connections to a particular village during sampling.

The quality of the water samples differed from one sampling point to another; this was highly attributed to seasonal variations due to rainfall. Therefore these variation in data may have differed if all the samples were collected on the same day and time.

Additionally, sanitary risk scores weighed all risks equally; however, it is likely that some factors may be more influential than others. A study in Uganda of protected springs determined that some of the sanitary risk factors have a stronger association with contamination than others (Parker, et al., 2010). The data obtained during this study showed that presence of latrine within 10 m proximity, poses higher risk compared to absence or inadequate fence around the tap stand. Also, low pressures in the network paired with low chlorine residual posed higher risk compared exposed pipes and signs of erosion along the distribution network.

5.4.8 Significance

These findings can be used by Bushenyi-Ishaka water supply system for risk management. Collective data on sanitary risks could help highlight potential key investments areas.

The findings of this study will increase scientific data available on microbiological contamination in WDNs of small towns.

The recommendations given on the SIF for piped distribution can be used to improve the usability and the effectiveness of the sanitary inspections as a tool for risk assessment.

Chapter 6 Conclusions and recommendations

6.1 Conclusions

A risk assessment of Bushenyi-Ishaka municipality water distribution network was carried out through the combination of sanitary inspections and water quality analysis. This research was motivated by the need to develop easy to use tools for risk assessment in the distribution network of small water supplies. The results showed that a sanitary inspection form is a useful tool for identifying risks. However, not all risk factors included in the checklist were applicable for Bushenyi-Ishaka municipality. Among the risks identified, low chlorine residual, low pressures in the networks, pipe bursts, and leaks and the presence of signs of pollution within 10 m of the tap stand were the risks that stood out and can be generalized for small water supplies.

The study also revealed that there is no statistical correlation between sanitary inspection forms and *E. coli* concentration. This means that there is no monotonic relationship whatsoever between sanitary inspections for piped supply and *E. coli* concentration. Further, a binary logistic model showed that sanitary inspections alone could not predict the presence or absence of *E. coli* coliforms in water. These results suggest that sanitary inspections alone cannot be used in place of microbiological water quality analysis.

The combined analysis was carried out at varying scale to determine an optimum scale of application for the SIFs. The results showed a minimal difference between the productivity at each scale. However, the risks at village scale are more specific to the specific problematic area.

Conclusively, the water safety situation in Bushenyi-Ishaka municipality WDN is not unique, but it depicts the common water safety problems among water supplies in small towns. In the bid to achieve safe and affordable drinking water, change of the water safety situation is a gradual process but the water supply companies should stay aware of the hazards and hazardous events in the distribution networks through frequent risk assessment and control.

6.2 Recommendations

6.2.1 Draft sanitary inspection form for piped distribution

1. Based on the piloted SIF draft, the risk factor on fencing around the tap stand should be investigated further to check its influence on microbiological water quality.
2. The reasons for the consideration of each risk factor should be explained to increase the user-friendliness of the SIF to the low level field operators.
3. Further research should be carried out on the influence of each risk factor in the sanitary inspection form on the presence or absence of *E. coli* concentrations.
4. The sanitary inspection form for piped distribution should be piloted on a smaller water supply system.
5. Also it is recommended to carry out sanitary inspections at a smaller scale of application to see if the risks identified can be more specific.
6. Some of the hazardous events are too general. Particularly, the risk factor on signs of pollution within 10 m of the tap stand is very general, it encompasses many risk factors that show high correlation with the presence of *E. coli* concentrations. It should be therefore split for to give better results.
7. According to the findings of this study, there is minimal difference between the productivity of the sanitary inspections at each scale. Therefore, the sanitary inspections for piped supply can be employed at any scale tested.

6.2.2 Water supply system

The NWSC staff should improve the compliance with operation and maintenance activities for the water supply system and ensure to follow routine maintenance duties such as cleaning of the reservoir and routine flushing. Also regarding the low chlorine residual in the distribution network, the water quality team should monitor the water quality in the water supply system to come up with an optimal chlorine dosage. Regarding the reservoir, the cleaning routine was overdue which shows lagging on maintenance issues.

Bushenyi-Ishaka, water distribution network, should be re-mapped, including the new water supply system from Kitagata treatment plant, through Kikuba reservoir and also show the new pipe extensions. The file used in this study was last updated in 2016 which leaves out many distribution pipes, and also the number of connections cannot be accurately estimated.

Running an EPANET model of the system will help balance pressures in the distribution network; the pressures in the network are imbalanced such that some areas have very high pressure while others have low pressure, hence the water does not reach the outlets. This may improve the hydraulic integrity in the network and in return improve the water quality. EPANET is an excellent tool to carry out a diagnostic analysis in the system; it will also help in determining the amount of disinfectant to be dosed depending on daily conditions. After installation of a chlorine boost station, the chlorine residual; in the distribution network improved, however, it is still below the minimum allowable value by WHO guidelines. It is therefore recommended that a vulnerability assessment in the distribution network is carried out to optimize the residual chlorine levels in the WDN. EPANET is a free software readily available all over the world. However, it requires skill and data to implement.

6.2.3 The municipality and the residents

Improve waste management: according to Nyakutsikwa (2018) there is 85% usage of latrines in Bushenyi-Ishaka municipality which are not lined. Hence the contents can easily seep through the soil and intrude piped water where there are pathways like leakage. The grey water drains are not well maintained, and at times greywater is directed directly to the environment. Also, the solid water is strewn all over clogging some of the valve chambers. They should reduce, reuse and recycle waste.

The tap owners should consider cleaning of the overhead tanks and carry out general maintenance around the tap stands.

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Appendices

Appendix A: sanitary inspection form for piped distribution

DRAFT Sanitary inspection form – Piped distribution

I. General information

a. Location:

Name of village/town	Commune	District	Province	State

National grid reference coordinates	GPS coordinates	Additional location information	Number of households served by this water supply

b. Date last water sample was taken:
(Use the table below to enter test results from the last water sample taken.)

Parameter tested	Faecal coliforms	Arsenic	Nitrate	Nitrite	Manganese	Lead
Date of test						
Result of test						

Additional test						
Date of test						
Result of test						

c. Weather conditions <u>during</u> inspection:
(Indicate temperature and precipitation conditions during the inspection by placing a circle around one option from each category.)

Temperature	<0° Celsius	0-15° Celsius	15-30° Celsius	>30° Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

d. Weather conditions during the week <u>prior</u> to inspection:
(Indicate temperature and precipitation conditions during the week prior to the inspection by placing a circle around one option from each category.)

Temperature	<0° Celsius	0-15° Celsius	15-30° Celsius	>30° Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

e. Water treatment prior to abstraction/collection?
(Answer the question by ticking (✓) the appropriate box and providing further information, where applicable.)

☐ No treatment applied prior to abstraction from pipe

☐ Other. Describe (e.g. method, frequency):

____

Note:

<u>1.</u> If other water sources are used by the community (e.g. point sources), carry out individual sanitary inspections for these as well.

II. Sanitary inspection form

IMPORTANT – READ FOLLOWING NOTES BEFORE UNDERTAKING SANITARY INSPECTION

***Notes*:**

1. *Answer the questions by ticking (✓) the appropriate box.*
2. *If there is no risk present, or a question does not apply to the well being inspected, tick the **NO** box. In this case, do not complete the risk level section and move on to the next question.*
3. *If a risk is present, tick **YES**. Consider if the situation is likely to threaten water quality/safety and how serious the consequences could be (e.g. if people could get sick), then circle the risk level as follows:*
   - *HIGH (very important, requires urgent attention and action);*
   - *MEDIUM (important, requires attention and action may be taken);*
   - *LOW (less important, no action required now).*
4. *For important situations that require attention, note actions to be taken. These notes can be used to develop a more detailed improvement plan, outlining what will be done, by whom, by when and what resources are required.*

	Sanitary Inspection Questions	NO	YES (risk)	Risk Level (circle risk **only** if **YES** is ticked)			What action is needed?
Reservoirs (including storage tanks)							
1	Is the reservoir open (i.e. uncovered), or if there is a cover, is it inadequate (e.g. cracked, damaged, leaking) to prevent contamination?	☐	☐	Low	Medium	High	
2	Is the reservoir structure damaged, cracked or leaking?	☐	☐	Low	Medium	High	
3	Is there any point of entry (e.g. air vent, overflow pipe, inspection hatch cover) to the reservoir that is inadequately covered or sealed to prevent contamination from entering?	☐	☐	Low	Medium	High	
4	Does the inside of the reservoir contain any visible signs of contamination (e.g. animal waste, sediment accumulation, scum, floating objects)?	☐	☐	Low	Medium	High	

DRAFT Sanitary inspection form – Piped distribution

5	Can water short-circuit from the inlet to outlet?	☐	☐	Low	Medium	High	
6	Is the fencing or barrier around the reservoir absent or inadequate to prevent contamination or unauthorized entry?	☐	☐	Low	Medium	High	
7	Can signs of sources of pollution be seen within 10 meters of the reservoir (e.g. latrines, animals, rubbish, open defecation)?	☐	☐	Low	Medium	High	
Public tapstands/private yard taps							
8	Are the tapstand/tap attachments (such as hoses etc.) unclean, damaged or leaking?	☐	☐	Low	Medium	High	
9	Is the drainage poor (e.g. absent or inadequate drainage channel), causing stagnant water in the tapstand/tap area?	☐	☐	Low	Medium	High	
10	Is the concrete floor around the tapstand/tap absent or inadequate to prevent contamination (e.g. cracked, damaged)?	☐	☐	Low	Medium	High	
11	Is the fencing or barrier around the tapstand/tap absent or inadequate to prevent contamination or unauthorized entry?	☐	☐	Low	Medium	High	
12	Can signs of sources of pollution be seen within 10 meters of the tapstand/tap (e.g. latrines, animals, rubbish, open defecation)?	☐	☐	Low	Medium	High	

General							
13	If there are any pressure break boxes/tanks, are their covers absent or inadequate to prevent contamination?	☐	☐	Low	Medium	High	
14	Are there any leakages visible between entry point to the distribution system and the point of delivery to the user (e.g. leaking pipes or valves, ponding water etc.)?	☐	☐	Low	Medium	High	
15	Are there any visible signs of illegal connections to the distribution system network?	☐	☐	Low	Medium	High	
16	Are there any exposed pipes visible in the system?	☐	☐	Low	Medium	High	
17	Are there any signs of erosion within the system that may compromise the integrity of any of the system components (e.g. near to pipes, break pressure boxes, values, reservoirs etc.)?	☐	☐	Low	Medium	High	

Enter the number of 'Low', 'Medium', 'High' risks and multiply by the relevant number to generate a 'Score'. The sum of the three scores is the 'Sanitary risk score'.

Risk level	Number of risks	Multiply by:	Score
# High		X 5	
# Medium		X 3	
# Low		X 1	
Sanitary risk score (max. 65)		**Total:**	

Draft 08 02 2018

III. Additional details, remarks, observations, photographs and recommendations

....

....

....

....

....

IV. Corrective actions agreed to be undertaken
(Where possible, remedial actions should focus on correcting the most serious risks first. Use additional sheets if required.)

Action #1: ....

Date action should be completed: ....

Name of person responsible for action: ....

Signature of person responsible for action: ....

Date: ....

Action #2: ....

Date action should be completed: ....

Name of person responsible for action: ....

Signature of person responsible for action: ....

Date: ....

Action #3: ....

Date action should be completed: ....

Name of person responsible for action: ....

Signature of person responsible for action: ....

Date: ....

V. Name of inspector: .... Designation of inspector: ....

Signature: .... Date: ....

VI. Name of water supply representative: ....

Signature: .... Date: ....

Appendix B: Basis of interviews with the NWSC staff

	Role of NWSC staff	**Content**
1	Technical manager	Maintenance and repair on the WDN, leakages, zoning of the network, and intermittency of water supply.
2	Commercial officer	The number of connections and how they are distributed.
4	Water quality personnel	Water quality and how it changes after treatment to the consumer tap. Also to understand water quality monitoring routine and give access to the data
5	Plant operator	To understand the general treatment process, production, and supply.

Table showing water quality data for Bushenyi-Ishaka municipality

Date of sampling	Sampling code	Location	Latitude	Longitude	Tap stand type	Free chlorine	pH	Turbidity	E. Coli
20/11/2018	1	Bwegiragye	-0.53813584	30.140015	yard tap stand	0.18	7.1	4.1	1.0
20/11/2018	2	Bwegiragye	-0.53652861	30.14059851	PSP	0.13	6.9	3.8	6.0
20/11/2018	3	Bwegiragye	-0.53555764	30.14036738	PSP	0.12	7.0	3.6	4.0
20/11/2018	4	Bwegiragye	-0.53338204	30.14785256	yard tap stand	0.11	6.8	2.5	6.0
20/11/2018	5	Bwegiragye	-0.53238027	30.13681276	yard tap stand	0.05	6.9	2.7	6.0
20/11/2018	6	Bwegiragye	-0.53137662	30.13619427	yard tap stand	0.1	6.9	2.8	4.0
20/11/2018	7	Kizinda	-0.53713785	30.12353461	PSP	0.12	7.1	2.7	13.0
20/11/2018	8	Kizinda	-0.53623328	30.12310594	PSP	0.04	7.0	2.1	6.0
20/11/2018	9	Kizinda	-0.53443233	30.1232777	PSP	0.19	7.0	2.4	9.0
20/11/2018	10	Kizinda	-0.53356612	30.12347419	PSP	0.04	7.0	2.9	65.0
20/11/2018	11	Kigoma	-0.52722876	30.12418882	school tap stand	0.16	7.4	3.3	5.0
20/11/2018	12	Kigoma	-0.521662°	30.121640°	PSP	0.25	6.9	2.1	6.0
20/11/2018	13	Kigoma	-0.518022°	30.119487°	yard tap stand	0.03	7.0	1.8	9.0
20/11/2018	14	Kigoma	-0.509078	30.114187°	PSP	0.08	6.8	3.2	4.0
04/12/2018	15	Bwegiragye	-0.53987	30.13921	yard tap stands	0.21	6.1	1.6	15.0
04/12/2018	16	Bwegiragye	-0.540149	30.1402	yard tap stands	0.13	6.0	4.3	27.0
04/12/2018	17	Bwegiragye	-0.53591	30.14137	yard tap stands	0.16	6.0	2.5	53.0
04/12/2018	18	Bwegiragye	-0.53476	30.13915	yard tap stands	0.07	6.2	1.9	231.0
04/12/2018	19	Bwegiragye	-0.53339	30.13745	yard tap stands	0.14	5.7	2.2	11.0

04/12/2018	20	Bwegiragye	-0.53107	30.1371	yard tap stands	0.32	5.9	1.1	2.0
05/12/2018	21	Bassajabalaba	-0.54087	30.14383	PSP	0.08	5.6	5.0	4.0
05/12/2018	22	Bassajabalaba	-0.54163	30.14329	private yard tap stands	0.14	5.5	31.2	10.0
05/12/2018	23	Bassajabalaba	-0.54215	30.14187	private yard tap stands	0.04	5.8	1.3	0.0
05/12/2018	24	Bassajabalaba	-0.54251	30.14094	PSP	0.28	5.7	1.6	0.0
05/12/2018	25	Ishaka	-0.54434	30.1398	PSP	0.03	5.7	2.0	0.0
05/12/2018	26	Kabiriisi	-0.5454	30.14061	PSP	0.1	5.3	5.2	237.0
05/12/2018	27	Kabiriisi	-0.54469	30.14069	PSP	0.09	5.3	5.6	0.0
05/12/2018	28	Kaburangye	-0.54172	30.12797	private yard tap stand	0.12	5.7	1.5	0.0
05/12/2018	29	Kizinda	-0.54047	30.12624	private yard tap stand	0.1	5.6	1.8	0.0
05/12/2018	30	Nyakatooma	-0.54438	30.13276	private yard tap stand	0.12	5.5	4.4	0.0
05/12/2018	31	Nyakatooma	-0.54747	30.12991	private yard tap stand	0.09	5.6	5.1	0.0
05/12/2018	32	Nyakatooma	-0.54733	30.12941	private yard tap stand	0.07	5.5	3.4	0.0
06/12/2018	33	Kikuba	-0.54945	30.17009	PSP	0.12	6.3	9.3	0.0

06/12/2018	34	Kikuba	-0.55113	30.16653	private yard tap stand	0.16	6.4	2.1	12.0
06/12/2018	35	Kikuba	-0.55079	30.16663	private yard tap stand	0.24	6.5	3.7	0.0
06/12/2018	36	Kikuba	-0.55421	30.16666	private yard tap stand	0.17	6.5	1.4	10.0
06/12/2018	37	Kikuba	-0.55478	30.16651	private yard tap stand	0.3	6.7	1.0	43.0
06/12/2018	38	Kikuba	-0.55482	30.16387	private yard tap stand	0.33	6.6	5.6	7.0
06/12/2018	39	Kikuba	-0.55572	30.16125	private yard tap stand	0.14	6.7	1.7	22.0
06/12/2018	40	Kikuba	-0.55551	30.16065	private yard tap stand	0.12	6.7	2.4	40.0
06/12/2018	41	Ruharo	-0.5645	30.15954	private yard tap stand				0.0
06/12/2018	42	Ruharo	-0.56455	30.1586	private yard tap stand	0.16	6.7	4.4	0.0
06/12/2018	43	Ruharo	-0.56475	30.15829	private yard tap stand	0.14	6.8	4.8	5.0
06/12/2018	44	Ruharo	-0.57155	30.15349	private yard tap stand	0.14	6.8	2.0	0.0

06/12/2018	45	Rukindo	-0.54084	30.16744	PSP	0.19	6.7	4.7	8.0
06/12/2018	46	Rukindo	-0.54104	30.168	PSP	0.23	6.7	4.2	0.0
06/12/2018	47	Nyabicherere	-0.54031	30.1669	private yard tap stand	0.23	6.7	5.4	0.0
10/12/2018	48	Nyabicherere	-0.53991	30.16789	private yard tap stand	0.06	5.5	2.0	0.0
10/12/2018	49	Nyabicherere	-0.53925	30.16868	private yard tap stand	0.13	5.2	2.1	0.0
10/12/2018	50	Nyabicherere	-0.53753	30.1694	private yard tap stand	0.1	5.6	2.7	0.0
10/12/2018	51	Nyabicherere	-0.53613	30.16927	private yard tap stand	0.09	5.8	1.0	0.0
10/12/2018	52	Nyabicherere	-0.53667	30.16903	private yard tap stand	0.13	5.7	2.1	0.0
10/12/2018	53	Nyabicherere	-0.5358	30.17148	private yard tap stand	0.1	5.7	3.7	0.0
10/12/2018	54	Nyabicherere	-0.53556	30.17209	private yard tap stand	0.1	5.3	2.9	0.0
10/12/2018	55	Nyabicherere	-0.53562	30.17239	private yard tap stand	0.24	5.9	1.8	0.0
10/12/2018	56	Nyabicherere	-0.53506	30.17194	private yard tap stand	0.1	5.3	4.6	0.0

10/12/2018	57	Nyabicherere	-0.53261	30.17161	private yard tap stand	0.19	5.7	1.0	34.0
10/12/2018	58	Nyabicherere	-0.53173	30.17106	private yard tap stand	0.17	5.5	2.1	18.0
10/12/2018	59	Nyabicherere	-0.5297	30.17112	private yard tap stand	0.07	5.8	2.3	0.0
10/12/2018	60	Rukindo	-0.54027	30.16594	private yard tap stand	0.11	5.7	2.6	40.0
10/12/2018	61	Rukindo	-0.54356	30.16361	private yard tap stand	0.19	5.9	1.8	0.0
10/12/2018	62	Rukindo	-0.54622	30.16209	private yard tap stand	0.29	5.8	1.9	0.0
10/12/2018	63	Rukindo	-0.54358	30.15877	private yard tap stand	0.1	5.8	1.5	0.0
11/12/2018	64	Nyabicherere	-0.53898	30.16773	private yard tap stand	0.47	6.6	87.3	58.0
11/12/2018	65	Nyabicherere	-0.54004	30.16673	private yard tap stand	0.15	6.8	19.2	15.0
11/12/2018	66	Nyabicherere	-0.53979	30.16642	private yard tap stand	0.24	6.8	33.2	14.0
11/12/2018	67	Nyabicherere	-0.5387	30.16685	private yard tap stand	0.31	6.4	10.0	0.0

11/12/2018	68	Nyabicherere	-0.53829	30.1665	private yard tap stand	0.04	6.5	22.8	0.0
11/12/2018	69	Nyabicherere	-0.53569	30.16591	private yard tap stand	0.03	6.8	9.4	0.0
11/12/2018	70	Nyabicherere	-0.53365	30.16394	private yard tap stand	0.2	6.7	30.3	0.0
11/12/2018	71	Nyabicherere	-0.53256	30.16216	PSP	0.56	6.6	91.1	0.0
11/12/2018	72	Nyabicherere	-0.53144	30.15935	private yard tap stand	0.19	6.7	11.2	0.0
11/12/2018	73	Nyabicherere	-0.53045	30.15939	private yard tap stand	0.06	6.7	1.6	0.0
11/12/2018	74	Bassajabalaba	-0.53324	30.16257	private yard tap stand	0.48	6.7	70.2	8.0
11/12/2018	75	Bassajabalaba	-0.53339	30.16217	private yard tap stand	0.11	6.8	53.2	0.0
11/12/2018	76	Bassajabalaba	-0.53402	30.16252	private yard tap stand	0.73	6.7	62.7	2.5
11/12/2018	77	Bassajabalaba	-0.53432	30.1617	private yard tap stand	0.1	6.4	1.8	0.0
11/12/2018	78	Bassajabalaba	-0.53455	30.1619	private yard tap stand	0.05	6.7	2.1	0.0

11/12/2018	79	Bassajabalaba	-0.53474	30.161	private yard tap stand	0.1	6.7	5.2	0.0
11/12/2018	80	Bassajabalaba	-0.53716	30.15948	private yard tap stand	0.02	6.9	1.8	0.0
12/12/2018	81	Rukindo	-0.54008	30.16414	private yard tap stand	0.02	6.9	1.4	1.5
12/12/2018	82	Rukindo	-0.5405	30.16106	private yard tap stand	0.11	6.9	1.3	4.5
12/12/2018	83	Rukindo	-0.54197	30.15775	private yard tap stand	0.09	6.8	1.3	2.5
12/12/2018	84	Rukindo	-0.54187	30.15704	PSP	0.07	6.9	1.4	1.0
12/12/2018	85	Rukindo	-0.54397	30.15679	private yard tap stand	0.19	6.8	1.3	0.0
12/12/2018	86	Rukindo	-0.54728	30.15555	private yard tap stand	0.07	6.7	1.0	0.5
12/12/2018	87	Rukindo	-0.54783	30.15504	private yard tap stand	0.24	6.7	0.8	79.0
12/12/2018	88	Rukindo	-0.54822	30.1551	private yard tap stand	0.23	6.9	1.0	0.0
12/12/2018	89	Rukindo	-0.54196	30.15508	private yard tap stand	0.33	6.6	0.8	0.0

12/12/2018	90	Rukindo	-0.54303	30.15412	private yard tap stand	0.14	6.5	0.9	0.5
12/12/2018	91	Rukindo	-0.54252	30.15491	private yard tap stand	0.19	6.6	0.7	0.0
12/12/2018	92	Rukindo	-0.53729	30.15893	private yard tap stand	0.32	6.8	5.4	0.5
12/12/2018	93	Rukindo	-0.53719	30.15803	private yard tap stand	0.28	6.8	5.6	1.0
12/12/2018	94	Rukindo	-0.53858	30.1554	private yard tap stand	0.13	6.6	0.9	1.0
12/12/2018	95	Bassajabalaba	-0.53936	30.14653	private yard tap stand	0.11	6.8	4.3	1.0
12/12/2018	96	Bassajabalaba	-0.53834	30.14735	private yard tap stand	0.17	6.8	4.6	14.0
12/12/2018	97	Bassajabalaba	-0.53803	30.14867	private yard tap stand	0.06	6.8	5.9	0.0
12/12/2018	98	Bassajabalaba	-0.53763	30.14946	private yard tap stand	0.09	6.7	4.2	0.0
10/01/2019	99	Kabiriisi	-0.54315	30.14097	private yard tap stand	0.06	6.1	1.9	0.0
10/01/2019	100	Kabiriisi	-0.54413	30.14069	private yard tap stand	0.18	6.2	3.6	1.0

10/01/2019	101	Kabiriisi	-0.54478	30.14208	private yard tap stand	0.19	6.1	1.7	0.0
10/01/2019	102	Kabiriisi	-0.54546	30.1416	private yard tap stand	0.11	6.0	1.4	0.0
10/01/2019	103	Kabiriisi	-0.54624	30.14174	private yard tap stand	0.16	5.6	1.0	0.0
10/01/2019	104	Kabiriisi	-0.54586	30.14196	private yard tap stand	0.08	6.2	1.3	0.0
10/01/2019	105	Kabiriisi	-0.54648	30.14034	private yard tap stand	0.13	6.2	8.1	0.5
10/01/2019	106	Kabiriisi	-0.54774	30.13939	private yard tap stand	0.27	6.3	4.0	0.0
10/01/2019	107	Kabiriisi	-0.54504	30.14016	private yard tap stand	0.09	6.3	0.8	0.0
15/01/2019	108	Rwemirokora	-0.54624	30.14415	private yard tap stand	0.05	7.3	1.6	0.5
15/01/2019	109	Rwemirokora	-0.54703	30.14358	private yard tap stand	0.01	7.3	1.3	0.0
15/01/2019	110	Nyakatooma	-0.54346	30.13331	private yard tap stand	0.13	7.2	1.6	0.0
15/01/2019	111	Kaburangye	-0.54181	30.13376	private yard tap stand	0.14	7.1	1.3	0.0

15/01/2019	112	Kaburangye	-0.54191	30.13212	private yard tap stand	0.24	7.1	1.2	0.0
15/01/2019	113	Kaburangye	-0.54085	30.13153	private yard tap stand	0.11	7.0	1.4	0.0
15/01/2019	114	Kaburangye	-0.53892	30.1309	private yard tap stand	0.16	7.1	3.0	0.0
15/01/2019	115	Kizinda	-0.53891	30.1267	private yard tap stand	0.13	7.1	2.0	0.5
15/01/2019	116	Kizinda	-0.53619	30.12763	private yard tap stand	0.01	7.0	6.9	3.0
15/01/2019	117	Kizinda	-0.53008	30.12952	private yard tap stand	0.12	7.1	1.8	0.5
16/01/2019	118	Nyakatooma	-0.54585	30.13587	private yard tap stand	0.01	7.1	1.1	3.5
16/01/2019	119	Nyakatooma	-0.54524	30.13591	private yard tap stand	0.01	7.2	1.7	0.0
16/01/2019	120	Nyakatooma	-0.54542	30.1353	private yard tap stand	0.01	7.0	1.0	0.0
16/01/2019	121	Nyakatooma	-0.5467	30.1334	private yard tap stand	0.09	7.0	1.0	1.5
16/01/2019	122	Nyakatooma	-0.54453	30.13384	private yard tap stand	0.04	7.0	1.1	1.0

16/01/2019	123	Nyakatooma	-0.54475	30.13211	private yard tap stand	0.06	6.8	0.6	1.5
16/01/2019	124	Nyakatooma	-0.54499	30.13202	private yard tap stand	0.1	7.2	1.3	1.0
16/01/2019	125	Nyakatooma	-0.54603	30.13061	private yard tap stand	0.04	6.9	0.7	0.0
16/01/2019	126	Nyakatooma	-0.54682	30.12966	private yard tap stand	0.05	6.9	1.4	0.0
16/01/2019	127	Nyakatooma	-0.55012	30.12744	private yard tap stand	0.05	7.1	0.9	0.0
16/01/2019	128	Nyakatooma	-0.55157	30.12679	private yard tap stand	0.05	7.0	0.9	0.0
17/01/2019	129	Kizinda	-0.53892	30.1259	private yard tap stand	0.12	7.1	1.4	0.0
17/01/2019	130	Kizinda	-0.53863	30.1251	private yard tap stand	0.05	7.0	1.1	2.5
17/01/2019	131	Kizinda	-0.5405	30.12409	private yard tap stand	0.13	7.0	1.5	6.5
17/01/2019	132	Kizinda	-0.54124	30.12249	private yard tap stand	0.25	6.9	1.5	3.0
17/01/2019	133	Kizinda	-0.54497	30.12319	private yard tap stand	0.19	7.0	1.4	0.0

17/01/2019	134	Kizinda	-0.54742	30.12107	private yard tap stand	0.3	7.0	1.5	0.0
17/01/2019	135	Kizinda	-0.54905	30.1212	private yard tap stand	0.23	6.8	2.0	0.0
17/01/2019	136	Kizinda	-0.54017	30.12027	private yard tap stand	0.17	7.0	1.0	4.0
17/01/2019	137	Kizinda	-0.54073	30.11839	private yard tap stand	0.11	6.8	2.0	0.0
17/01/2019	138	Kizinda	-0.54274	30.11858	private yard tap stand	0.03	7.0	2.0	0.0
17/01/2019	139	Kizinda	-0.53881	30.12302	private yard tap stand	0.12	7.0	1.0	5.5
17/01/2019	140	Kizinda	-0.53566	30.12625	private yard tap stand	0.53	6.9	1.0	6.5
02/02/2019	141	Kabiriisi	-0.54551	30.1412	private yard tap stand	0.08	6.7	5.0	8.5
02/02/2019	142	Kabiriisi	-0.54896	30.13969	private yard tap stand	0	6.6	7.0	22.0
02/02/2019	143	Kabiriisi	-0.54876	30.13923	private yard tap stand	0.19	6.4	5.0	12.0
02/02/2019	144	Ishaka	-0.54948	30.13863	private yard tap stand	0.2	6.5	2.0	3.0

02/02/2019	145	Ishaka	-0.54668	30.13892	private yard tap stand	0.11	6.4	7.0	9.0
02/02/2019	146	Kizinda	-0.53829	30.12521	private yard tap stand	0.16	6.6	3.0	12.0
02/02/2019	147	Kizinda	-0.53757	30.12435	private yard tap stand	0.24	6.6	3.0	1.5
02/02/2019	148	Kizinda	-0.53744	30.12301	private yard tap stand	0.29	6.5	4.0	14.0
02/02/2019	149	Kizinda	-0.53739	30.12246	private yard tap stand	0.31	6.5	3.0	0.5
02/02/2019	150	Kizinda	-0.53778	30.12019	private yard tap stand	0.1	6.7	5.0	14.0
02/02/2019	151	Kizinda	-0.53689	30.11835	private yard tap stand	0.38	6.7	4.0	8.5
02/02/2019	152	Kizinda	-0.53561	30.11776	private yard tap stand	0.18	6.7	9.0	9.0
02/02/2019	153	Kizinda	-0.53642	30.11912	private yard tap stand	0.47	6.7	5.0	8.5
02/02/2019	154	Kigoma	-0.52041	30.12303	private yard tap stand	0.23	6.6	14.0	0.5
02/02/2019	155	Kigoma	-0.5165	30.12349	private yard tap stand	0.06	6.8	3.0	0.0

04/02/2019	156	Rwemirokora	-0.55403	30.14376	private yard tap stand	0.11	6.8	2.7	2.5
04/02/2019	157	Rwemirokora	-0.54747	30.1428	private yard tap stand	0.05	6.5	2.4	8.5
04/02/2019	158	Rwemirokora	-0.54785	30.14368	private yard tap stand	0.12	6.5	2.4	8.0
04/02/2019	159	Rwemirokora	-0.54832	30.14537	private yard tap stand	0.32	6.5	2.4	7.5
04/02/2019	160	Rwemirokora	-0.54748	30.14476	private yard tap stand	0.18	6.3	3.4	632.0
04/02/2019	161	Rwemirokora	-0.54883	30.1428	private yard tap stand	0.21	6.3	4.1	15.0
04/02/2019	162	Rwemirokora	-0.5485	30.14235	private yard tap stand	0.05	6.5	3.1	11.0
04/02/2019	163	Ishaka	-0.54545	30.13841	private yard tap stand	0.43	6.3	2.4	0.5
04/02/2019	164	Ishaka	-0.54958	30.13642	private yard tap stand	0.09	6.4	2.5	1.0
04/02/2019	165	Ishaka	-0.54928	30.13445	private yard tap stand	0.04	6.3	4.6	14.0
04/02/2019	166	Ishaka	-0.55003	30.13554	private yard tap stand	0.32	6.6	2.2	6.0

04/02/2019	167	Rwemirokora	-0.54745	30.14443	private yard tap stand	0.12	6.9	1.3	3.0
04/02/2019	168	Rwemirokora	-0.54856	30.14425	private yard tap stand	0.05	6.6	1.9	6.0
04/02/2019	169	Rwemirokora	-0.55346	30.14362	private yard tap stand	0.36	6.4	2.6	0.0

Sample sanitary inspections and the risk scoring

no.	question	NO	YES	risk level	evaluation	quantity	NO2	YES3	risk level2	evaluation3
1	Is the reservoir open (i.e. uncovered), or if there is a cover, is it inadequate (e.g. cracked, damaged, leaking) to prevent contamination?	NO				1	NO			
2	Is the reservoir structure damaged, cracked or leaking?		YES	LOW	monitor the cracks and in case they become big in size repairs should be done.			YES	LOW	monitor the cracks and in case they become big in size repairs should be done.
3	Is there any point of entry (e.g. air vent, overflow pipe, inspection hatch cover) to the reservoir that is inadequately covered or sealed to prevent contamination from entering?		YES	HIGH	the inspection hatch is left uncovered thus leaves a pathway for contamination. It should be closed every after inspection.			YES	HIGH	the inspection hatch is left uncovered thus leaves a pathway for contamination. It should be closed every after inspection.
4	Does the inside of the reservoir contain any visible signs of contamination (e.g. animal waste, sediment accumulation, scum, floating objects)?	NO					NO			
5	Can water short-circuit from the inlet to outlet?		YES	LOW	the inlet is at the top and the outlet is close to the ground so very low chances of short circuit about a buffling factor of 0.3			YES	LOW	the inlet is at the top and the outlet is close to the ground so very low chances of short circuit about a buffling factor of 0.3
6	Is the fencing or barrier around the reservoir absent or inadequate to prevent contamination or unauthorized entry?	NO					NO			
7	Can signs of sources of pollution be seen within 10 meters of the reservoir (e.g. latrines, animals, rubbish, open defecation)?	NO					NO			
8	Are the tapstand/tap attachments (such as hoses etc.) unclean, damaged or leaking?		YES	low	the hose attached was tied to the tap with a dirty rubber thread. It is important to keep it clean.	1	NO			
9	Is the drainage poor (e.g. absent or inadequate drainage channel), causing stagnant water in the tapstand/tap area?		YES	medium	some didnt have a drainage channel while others had inadequate channel, others were wet or with ponding water around the tap.	9		YES	medium	some didnt have a drainage channel while others had inadequate channel, others were wet or with ponding water around the tap.
10	Is the concrete floor around the tapstand/tap absent or inadequate to prevent contamination (e.g. cracked, damaged)?		YES	high	most of the tap stands have no concrete floor thus poor drainage. Nonetheless, most have bricks arranged aroung the tap to place the jerrican on it when fetching water.	11		yes	high	most have no concrete floor and 3 were damaged
11	Is the fencing or barrier around the tapstand/tap absent or inadequate to prevent contamination or unauthorized entry?		YES	MEDIUM	there is no fence around the tapstands in these rural areas yhus at risk of access ny animals. They all have a lock to avoid unauthorised consumption.	12		YES	MEDIUM	there is no fence around the tapstands in these rural areas yhus at risk of access ny animals. They all have a lock to avoid unauthorised consumption.
12	Can signs of sources of pollution be seen within 10 meters of the tapstand/tap (e.g. latrines, animals, rubbish, open defecation)?		YES	low	kikuba is not highly populated	1- animal, 1- rubbish		YES	high	highly at risk of faecal contamination
13	If there are any pressure break boxes/tanks, are their covers absent or inadequate to prevent contamination?	NO			there are many washouts, air valves and gatevalces on the main and they are well covered.		NO			
14	Are there any leakages visible between entry point to the distribution system and the point of delivery to the user (e.g. leaking pipes or valves, ponding water etc.)?		YES	high	there is ponding water in aswamp where animals graze and the pipe passes and is left uncovered.	1	NO			
15	Are there any visible signs of illegal connections to the distribution system network?	NO			no suspicious connections observed		NO			
16	Are there any exposed pipes visible in the system?		YES	high	the place where they are exposed, there is high risk to pysical damage,the pipes have joints and there are animals grazing so gighly at risk of pathogen intrusion.	4	NO			
17	Are there any signs of erosion within the system that may compromise the integrity of any of the system components (e.g. near to pipes, break pressure boxes, values, reservoirs etc.)?	NO					NO			
		LOW	**4**					**LOW**	**2**	
		MEDIUM	**6**					**MEDIUM**	**6**	
		HIGH	**20**					**HIGH**	**12**	
		TOTAL	**30**					**TOTAL**	**20**	