KABALE UNIVERSITY
"Knowledge is the future"

Department of Civil Engineering

RESEARCH PROPOSAL

Spatiotemporal Assessment and Modelling of Roof-Harvested Rainwater Quality in Kigezi Highlands, Uganda

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1.0 INTRODUCTION

Water is an everlasting free resource that is vital for life (Rahman, *et al*., 2014). Access to water supply is essential to good life and health. It is crucial and pivotal to many other goals highlighted in the United Nation's Sustainable Development Goals (SDGs). Sustainable access to water for potable and non-potable uses continues to pose enormous challenges. The challenge of achieving water security in Africa is contingent upon the hydrological variability and its extremes (UN-Water, 2010). However, the availability of freshwater resources has become a major challenge facing humanity worldwide especially in developing countries. This situation has further been aggravated by a high rate of urbanization, population growth, rising water demand, continuous depletion of fresh surface water and groundwater, climate change, water governance, extreme social inequality and pollution (Struk-Sokolowska, *et al*., 2020, Balogun *et al.,* 2016). These situations require that water resources be satisfactorily managed in terms of quantity and quality to meet the current demands and attain future sustainability.

Rainwater harvesting is a promising and sustainable renewable resource for surface and groundwater at different scale level and scope.

It's imperative to note that there is ever increasing stress on freshwater resources due to rising demand leading to water scarcity in many places. The global uneven distribution of both population density and water resources is another key factor contributing to the stress. The scarcity of water thus has prompted people to prospect for new techniques of ensuring the provision of sufficient water for drinking, cooking, irrigation, flushing and gardening. One of those enhanced and alternative solutions to chronic shortage of water resources is Rainwater Harvesting (RWH) (Sturm *et al*., 2009; Bulcock and Jewitt, 2013). Okeola *et al.* (2022) opined that RWH is a promising and sustainable renewable resource for surface and ground water at different scales and scopes This method is indeed one of the most crucial means of water conservation in the world today, especially in arid and semi-area regions (Rahman, *et al*., 2014). RWH is increasingly being recognized as a likely viable option in regions experiencing dry periods, acute shortages, urbanization, irregular water supplies or non-connection to municipal water distribution network (Ammar *et al.,* 2016).

The usefulness of RWH notwithstanding, the monitoring and assessment of harvested water quality is now becoming of great concern because of the potential health risk that may be caused by physical, chemical and microbiological contamination during the process of harvesting. Over the last years, there have been different studies in USA, India, New-Zealand, Nigeria, Zambia, Brazil, Canada, Australia, England and South Korea to assess the quality of harvested rainwater. Majority of these studies reveal that rainwater harvesting is a viable option for water supply; however, it has an unacceptable levels of microbiological contamination and has unregulated physicochemical qualities (Fewtrell & Kay, 2007; C. Vialle *et al*, 2012). Harvested rainwater pollutants are intercepted in the atmosphere and some others are washed away from roofing materials (Struk-Sokołowska *et al*., 2020)

Some of researches at international level have assessed the quality of rainwater collected and stored soon after the rainfall. However, Radaideh *et al*. (2009) opined that there may be changes in water quality if stored for a long time. This assertion was also corroborated by Struk-Sokołowska *et al*. (2020). In another study, it was revealed that although rainwater is initially potable, but, microbiological and chemical contaminants may result from the long periods of storage (Kus *et al*., 2010). Extensive literature survey conducted reveal that, in Uganda, there is very scarce research that investigated the quality of harvested rainwater. The national body responsible for water distribution, National Water and Sewerage Corporation (NWSC) has not done studies geared towards improving rainwater systems as they are mainly concerned with piped water from both surface and underground sources. However, the physicochemical and microbiological parameters of this rainwater need to be ascertained as they are key factors affecting human health.

Since Kigezi highlands in South Western Uganda depend largely on the rainwater to meet their daily demand, it's imperative to investigate the spatiotemporal quality changes in the rainwater obtained from different catchments and stored in different tanks for quality assurance.

2.0 LITERATURE REVIEW

Rainwater harvesting is a very traditional and sustainable method which has been used for the provision of portable and non-potable water in residential and commercial buildings. This has consequently reduced the pressure on main water supplies hence enhancing green living (Rahman *et al*., 2014).

Advantages of rainwater harvesting include: reducing the burden on the public water supply, thus mitigating the water crisis, it can be used in case of an emergency such as fire, it is cost-effective as installation cost is low, recharging groundwater levels, thus preventing the depletion of aquifers, controlling water logging problems, preventing flooding, reducing soil erosion and helping to control climate change impacts (*Selala et al*., 2018). All these advantages promote RWH as an easily accessible and sustainable source of fresh water which can be implemented locally and internationally for securing water in water-scarce areas around the world. These systems could be upgraded and utilized to supply water on a large scale if the water-quality is satisfactory (Struk-Sokołowska *et al*., 2020).

The monitoring and assessment harvested rainwater is now becoming of great concern because of the potential health risk that may be caused by chemical and microbiological contamination (Vialle *et al*, 2012).

In developed countries, every nation has instituted a different approach concerning the use of rainwater owing to differing needs of the specific country. For instance, in France, only external uses (irrigation, house cleaning, etc.) were allowed, except of course when there is dire need such as in droughts or when there is no mains network (Vialle *et al*., 2012). Nevertheless, the perspective has since changed after assessing the potential of RWH. The country has invested in assessing the quality of harvested rainwater before it can be used. The government introduced a tax reduction to encourage the use of rainwater.

In the UK, storage and use of rainwater for domestic use is traditional and very popular. In Germany, almost one third of all new buildings use rainwater for all domestic use and the government funds all such initiatives. Also in Spain, the authorities launched a national program for subsidies. Similarly, other countries such as Italy, Sweden, Austria, Switzerland, Denmark, and Belgium hiked the prices of drinking water to encourage the use of rain water (Struk-Sokołowska *et al*., 2020).

Over the last years, there have been different studies in USA, India, New-Zealand, Nigeria, Zambia, Brazil, Canada, Australia, England and South Korea to assess the quality of harvested rainwater. Many of such studies have found out that though RWH is a viable option for domestic water supply, it has unacceptable levels of microbiological contamination and has unregulated physicochemical qualities (Vialle *et al*, 2012).

Rainwater from the skies is generally free from pollution. However, the harvested rainwater pollutants are intercepted in the atmosphere and some others are washed away from roofing materials (Struk-Sokołowska *et al*., 2020). It's also true that water changes its quality when collected and detained in storage tanks (*Selala et al*., 2018)

The majority of research studies in the area of water quality have assessed the quality of rain water collected soon after the rainfall, yet it is probable that there is a change in water quality if water is stored for a long time (Radaideh et al, 2009). Jamal did a study that investigated such water's quality after its collection and storage. The study was able to quantify and identify the sources of contamination such as industrial, agricultural and other urban activities. The other sources included biomass burning, livestock and fertilizer use and the quality of the catchment area.

Studies by (Efe, 2006) investigated the quality of harvested rainwater from roofs made of varying materials of aluminium, corrugated iron sheets, asbestos and thatch. It was established that rain water harvested from roofs meets the World Health Organization (WHO 2011) guidelines for drinking water, except for pH, total dissolved solids, color and iron. But, (Kus, et al., 2010), discovered that although rainwater is initially potable, microbiological and chemical contaminants may result from the long periods of storage. He pointed the need for periodical assessment during the time in the dry season when water is being utilized.

The microbiological quality of water is a key factor because it is relationship with health risks associated with rainwater. Therefore, it important to study and investigate microbiological quality changes of rainwater stored in the tanks. Many authors confirm that conditions such as detention duration, the season in which rainwater is collected, and roof type among others, greatly affect rainwater quality (Zdeb, et al., 2021).

A study by (Radaideh, et al., 2009) in on Quality assessment of Harvested Rainwater for Domestic uses in which 94 rainwater samples were collected from different storage tanks and analysed for various parameters such alkalinity, turbidity, PH, COD, NO_3, NH_4, Hardness, Pb, Fe, PO4, Cr and biological contaminants indicated that water varies depending on catchment area, location and availability of sanitary systems. It concluded that rainwater is unsafe for drinking because it contains microbes. This water could however be used for irrigation and other purposes. In this study however, samples were taken from different tanks and the analysis was not periodical. The study recommended that stored water quality should be analysed regularly and the catchment area should be seasonally cleaned. The study also recommended that stored water could be disinfected with chlorine before being used directly for drinking

Another study by (Utsev, 2012) on variability of Rainwater Quality due to Roof characteristics in which six sampling sites in Gboko Nigeria were selected and water samples tested for Alkalinity, pH, NO_3^-, SO_4^{2-}, NH_4^+, Ca^{2+} and Mg^{2+}, dissolved heavy metals (Fe, Cu, Mn, Zn, Ni and Cr), but total coliform was not detected. The study also discovered that the period of rainfall, environmental factors, type and age of roofing materials have varying effects on the characteristics of rainwater. It recommended that the roof drainage water quality in Gboko be used as grey water for domestic purposes but requires treatment to be used as drinking water. However, the study did not test the parameters of stored water and used different roofing materials

Vialle *et al.* (2012) conducted a study on Water Quality Monitoring and Hydraulic Evaluation of a Household Roof Runoff Harvesting System in France in which twenty-one (21) physicochemical parameters were screened using standard analytical techniques and microbiological quality of stored roof runoff investigated. Total coliforms, Escherichia Coli, enteroccocci, cryptospridium oocysts, Giardia cysts, Legionella species, Legionella pneumophila, aeromonas, and Pseudomonas aeruginosa were analysed. Chemical and microbiological parameters fluctuated during the course of the study, with the highest levels of microbiological contamination observed in roof runoffs collected during the summer. Overall, the collected rainwater had a relatively good physicochemical quality but variable, and, did not meet the requirements for drinking water and a microbiological contamination of the water was observed. However, the study did not investigate the quality of the water over a period of time.

In another study by (Rahman, et al., 2014) on sustainability of RWH system in terms of Water quality, water samples were collected from the selected residential building with a RWH system using laboratory prepared plastic bottles. The quality of harvestable water was checked considering several parameters such as pH, faecal coliform, total coliform, total dissolved solids, turbidity, NH_3–N, lead, and BOD_5. Two different collecting points were considered: water collected before entering into the storage tank (called first flush water) and water collected from the storage tank (tank water). From the results, the pH level of collected water did not pose any threat to water quality. The number of total coliforms present in the water was quite low initially, but after, a large number of total coliform grew in both flash and tank water. TDS were quite lower than the standard limit. Rainwater could be considered satisfactory from an aesthetic point of view. NH_3–N level was quite below the standard limit, BOD_5 became less in flash water than in tank water. Due to the lack of proper maintenance, BOD_5 increased in the tank water. Further treatment may make water more usable for household work. Lead concentration always remained below the standard. The study concluded that the overall quality of water was quite satisfactory as per Bangladesh standards.

Selala *et al.* (2018) compared the Chemical Quality of Rain Harvested Water from Roof and Surface Runoff Systems. Samples of rainwater were collected once from 51 households during the dry spell and assessed for specific chemicals' concentrations. The parameters studied were electrical conductivity, Sulphates, Phosphates, Nitrates, Turbidity, Boron, Sodium, Aluminium, Dissolved Organic Carbon, Nickel, Copper, Manganese, Calcium, Potassium, Cardium, Arsenic, Lead, Iron, Zinc, Chromium and Selenium. The results showed that the water from metallic roofs didn't meet WHO guidelines for drinking water. This was attributed to high concentrations of zinc. In addition, no periodical assessment was conducted.

Struk-Sokolowska *et al*. (2020) in a study on *The Quality of Stored Rainwater for Washing Purposes* used a tightly closed underground tank of PE in which the water stayed for 30 days and analyses were made after every 10 days. The parameters tested were; PH, Alkalinity, Hardness, Conductivity, Turbidity, Colour, TDS, TSS, DO, BOD, COD, KMnO4, SO4, Total Nitrogen, Total Phosphorous, Phosphates, Ammonium Nitrogen, Nitrate Nitrogen, Chloride, Cadmium, Calcium, Chromium, Copper, Iron, lead, Magnesium, Nickel, Potassium and Zinc. The concentration of all parameters analysed was lower than those specified for safe water, except for turbidity. It was concluded that detention of rainwater in the tank changes parameters in a safe range. However, this study used an underground tank which eliminated the effects of varying temperatures from sunshine or interactions with light.

In a study on an investigation of microbiological quality changes of roof harvested water stored in the tanks conducted by Zdeb *et al*. (2021), rainwater was collected depending on different collection conditions (type of roof surface, storage duration and season) and stored in HDPE canisters. Samples were kept at a temperature 12°C with no access to light to simulate underground tank conditions and analysed for Turbidity, NNH_4, NNO_2, NNO_3, PO_4 and TOC. Analysis of samples were done after every two weeks for three months. Results indicated that rainwater harvested from galvanized steel sheet and that collected in autumn and spring obtained the best micro biological quality. A decrease in the number of bacteria was observed in correlation with storage duration. The water became sanitary safe after six weeks at a storage temperature of 12°C. Its use for purposes requiring drinking before six weeks required disinfection.

Vasudevan and Natarajan (2021) by use of questionnaires to infer basic information on rainwater harvesting features, water quality and conservation, economics of implementation and financial support revealed that most respondents agreed that stored water is to be treated before direct consumption either by boiling, carbon filter or by RO filter. It is very important to maintain the required quality of stored water with longer shelf life.

3.0 STATEMENT OF THE PROBLEM

Due to the geographic location of Kigezi highlands in Uganda, it is expensive to receive water from municipal water supply even if it were available in the region. Thus, many people living in the Kigezi highlands depend largely on the harvested rainwater for all their water needs. The water collected from their rooftops which are mainly galvanized iron is stored in either concrete tanks or household equipment such as sauce pans, cisterns and jars for short-term use. This water is usually used sparingly so that it gets them throughout the dry season. However, the potential health risks associated with the quality of water stored for such long periods of time in tanks need to be investigated. It could be insinuated that the nature of the catchment (rooftop materials), containers' material and many other factors could have impaired the quality of the harvested water. Thus, this study intends to investigate the spatiotemporal variations in qualities of water taken from different types of catchments (rooftop materials) that are stored in different tank materials.

4.0 OBJECTIVES

The overall objective of this research is to investigate the spatiotemporal variability in qualities of roof-harvested rainwater in Kigezi Highlands, Uganda.

The specific objectives are to:

1. Experimentally evaluate the physical, chemical and bacteriological water quality of the samples of harvested and stored rainwater;
2. Investigate the level of purity of roof-harvested rainwater from different rooftops and tank materials as compare with the WHO and Uganda drinking water standards; and
3. Develop a model and establish correlation matrix between retention time and water quality.

5.0 RATIONALE/JUSTIFICATION

This study focuses on the spatiotemporal evaluation of quality of harvested rainwater in the mountainous areas of Kigezi Sub-region in Uganda. It is worthy to note that majority of the rural communities in this area are not connected to national water supply grids and the costs of prospecting other source of water resources are comparatively high. This is due to the fact that the geographical location of the study area makes the supply of water by National Water and Sewerage Corporation (NWSC) expensive. As a result, rainwater becomes the major source of water and in some places the only source of water to satisfy the people's need. In the literature survey, there is evidence of scarcity of literature on the evaluation of the quality of harvested rainwater in Uganda. In fact, NWSC is yet to conduct studies towards improving rainwater systems. Due to extensive exploration and dependence on harvested rainwater, there is strong need to evaluate the spatiotemporal variability in water quality parameters in Kigezi Sub-region. The physicochemical and microbiological quality of rainwater is a key factor because of its relationship with human health. Thus, the study will be beneficial in ascertaining the quality of this rainwater and probably recommend the level of treatment if found necessary. This study would contribute towards achieving the United Nation Sustainable Development Goals (SDGs) #3 themed “good health and wellbeing” and SDG #6 themed “clean water and sanitation”.

6.0 METHODOLOGY

The methodology that will be adopted for this research will be to obtain water samples from roof-harvested storage containers and subject these samples to both the physical, chemical and bacteriological quality analyses. The results shall be used to ascertain the potability of the harvested rainwater by comparing the results of water quality parameters obtained with Uganda drinking water standards and World health Organization (WHO). Furthermore, the results shall be modelled and statistically analysed to establish a correlation matrix between retention time and the quality of the water.

In order to ensure a high quality and reliability of water quality results, water quality samples will be collected in a manner that follows the standard procedure of the U.S Geological Survey of collection, preservation and analysis of the water samples.

This study shall follow the methodological framework in Figure 1. As indicated, the study entails three broad activities namely field work, laboratory work and desk study. The field works require elaborate reconnaissance survey for the identification of different catchments and storage containers available in the study area. This would assist in selection of the sampling points. More so, Geographic Positioning Systems (GPS) survey shall be conducted to record the spatial locations (coordinates) of the sampling points. The laboratory works shall involve evaluation of the physical, chemical and bacteriological parameters of the harvested rainwater. Lastly, the desk-study shall involve spatiotemporal analyses of the water quality parameter and development of models and establishing relationship between retention time and the quality of the stored water.

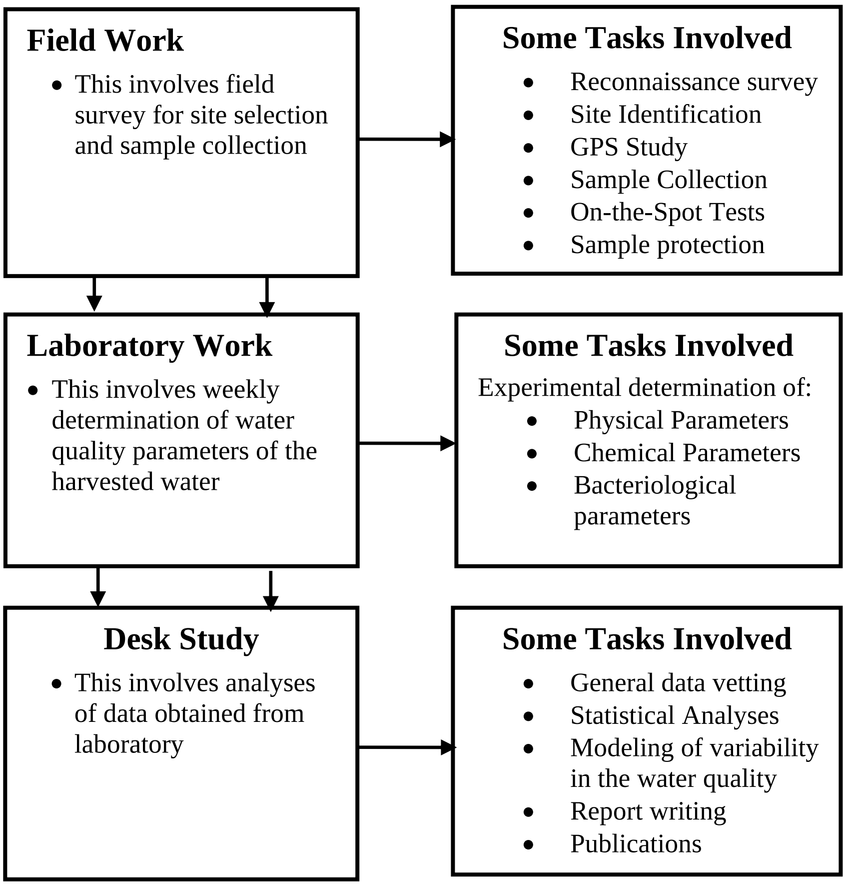

Figure 1: The Proposed Methodological Framework

6.1 Obtaining water samples from roof harvested storage reservoirs

6.1.1 Preparation prior to sampling

Before the sampling event, it will be ensured that the following are in place: a field book and field observation data sheet, a list and description (with GPS coordinates) of sampling locations, copy of sampling procedure, cooler for carrying the samples, ice packs, sample bottles, GPS, disposable sampling gloves and a sample submission form.

6.1.2 Sample labelling

Each sample bottle will be labelled with the appropriate field number and analysis package with a permanent marker ensuring that the field numbers on the sample bottles matches the field number in the field book and on the laboratory sample submission form.

Figure 1: Example of labelled sample bottle (Source: xxx)

A list of water sample monitoring locations will be developed indicating the site code, site name, latitude and longitude as in Table 1 below.

Table 1: Water sample monitoring locations

Site code	**Site name**	**Latitude**	**Longitude**

6.1.3 Sample collection

Samples shall be collected at the specified sites identified during the reconnaissance survey. Water samples shall be collected from different catchments (rooftops materials) and storage (reservoir materials). All field documentation and observations will be recorded in a field book and on field observation sheets before leaving the site.

The information to be documented will include: the name of the person doing the sampling, date and time of sample collection, sample observations and descriptions of anything unusual about the water such as dead animals (lizards, birds, insects and the like), foam, odours, unusual water colour, debris and presence of suspended surface matter.

Each time a sample is taken, it will be ensured that the samplers’ hands are clean, free of grease, debris or other substances like food or drink. Caps will be kept on sampling bottles until the sample is taken. Nothing will be placed inside the bottle except the water sample. The inside of the bottles and the lids will not be allowed to contact any surface during the course of sample collection.

The water will be entered into the sample bottle by placing the bottle 6 inches below the water surface.

6.1.4 Sample transportation

Samples will be delivered to the laboratory within 24 hours of sampling to have the analysis performed. Preservation of bacterial samples will involve capping the bottles tightly, cooling the bottles immediately on ice and keeping them cool until they reach the laboratory.

6.1.5 Quality Assurance and Quality Control

For every sampling trip, a field and trip blank will be included. Field blanks of distilled water will be filled in the field. These will help indicate contamination from handling or air contaminants. Field blanks will be handled the same way a regular blank will be handled by exposing the distilled water to the air for the same period of time the original sample was exposed.

Trip blank bottles will be filled with distilled water prior to leaving for the sampling trip. Trip blanks will be used to detect contaminants from the sampling container or other sources during transportation and storage. Trip blanks will remain unopened throughout the course of the sampling exercise. They will be subjected to the same transportation and storage conditions as the rest of the samples and will also be subjected to analysis.

6.2 Water quality analysis

The collected water samples will be analysed as soon as they reach the laboratory. Samples will be analysed for physical, chemical and bacteriological characteristics following the World Health Organization’s and Ugandan standards for drinking water. The samples shall be tested immediately after collection (on-the-spot testing for some selected parameters) and at intervals of week for a period of three months for temporal evaluation and modelling of the variability of water quality parameters.

6.2.1 Physical Characteristics

The physical characteristics that will be analysed are:

(a) pH

One of the most important indicators for water quality is its pH level. Although pH is considered an aesthetic water quality, the U.S. Environmental Protection Agency (EPA) recommends a pH between 6.5 and 8.5 for drinking water. A pH meter will be used to measure pH levels in the water. The water testing will be done in the lab using a benchtop meter.

(b) Conductivity

Conductivity is a measure of the ability of water to pass an electrical current (United States Environmental Protection Agency, 2012). Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminium cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius (25 C) (United States Environmental Protection Agency, 2012).

Conductivity is useful as a general measure of water quality since significant changes in conductivity could be an indicator that some source of pollution has entered the water. It will be measured with a probe and a meter. Conductivity is measured in micromhos per centimetre (µmhos/cm) or microsiemens per centimetre (µs/cm). For quality control, distilled water has a conductivity in the range of 0.5 to 3 µmhos/cm.

(c) Colour

Colour in roof-harvested water may result from the presence of natural metallic ions (iron and manganese), dust from the roof, debris, bird droppings and leaves. Colour will be determined by visual comparison of the sample with known concentrations of coloured solutions by observing sample colour by filling a matched nessler tube to the 50-mL mark with the water sample and comparing it with standards (American Public Health Association, 1992).

(d) Taste and odour

Taste and odour in roof-harvested rainwater can originate from corrosion or presence of natural inorganic and organic chemical contaminants on the harvesting surface and biological sources or processes (such as aquatic microorganisms) during storage as a result of microbial activity.

Taste and odour of the samples will be determined in accordance with IS: 10050 - Specifications for Drinking Water.

For cold odour: A 500ml flask will be filled with around 200ml of sample. The stopper will then be closed and the flask shaken well at room temperature. The flask will then be opened and smelt at the mouth of the flask. The odour will then be recorded in terms of the classifications in Table 2.

For hot odour: The intensity of the cold odour may be very low and cannot be detected. For this purpose, the flask will be heated to around 58-60°C, when closed with a stopper. The stopper will then be removed and smelt at the mouth of the flask. The odours will be detected by a group of observers as single observation may not be correct and judgement made depending on how many agree to a common odour.

The intensity of the odour will be determined on its strength and numbers assigned as follows; 0: No odour, 1: Very Faint, 2: Faint, 3: Distinct, 4: Decided or 5: Very Strong and the results added in a tabular form as indicated below.

As far as taste is concerned, it should be noted only when the full portability of water is ascertained, i.e. it should be free from all impurities (Physical, Chemical and Biological).

Table 2: Classification of odour and taste

Sample No.	**Date**	**Cold odour intensity**	**Hot odour intensity**	**Classification of taste**	**Remarks**

(e) Turbidity

Turbidity of water refers to the cloudiness of the water and it is a qualitative characteristic which is imparted by solid particles obstructing the transmittance of light through the water sample. Turbidity often indicates the presence of dispersed and suspended solids like clay, organic matter, silt, algae and other microorganisms.

The turbidity of the water samples will be measured using a turbidity tube. This is a tube with a black cross at the bottom and the water will be poured into the tube until when one can no longer make out the black cross at which point the scale, outside of the tube in NTU, will be read off.

(f) Suspended matter

Suspended matter in the samples will be determined using EPA method 160.2 in which a well-mixed sample will be filtered through a glass fibre filter, and the residue retained on the filter will be dried to constant weight at 103-105°C. The filtrate from this method will be used to determine the non-filterable residue in the water.

6.2.2 *Chemical Characteristics*

The chemical characteristics that will be analysed are:

(a) Total Hardness

Current laboratory practices define total hardness as the sum of divalent ion concentrations, especially those of calcium and magnesium, expressed in terms of mg $CaCO_3$/L. There are no known adverse health effects of hard or soft water, but the presence of hard waters results in two economic considerations: (1) hard waters require considerably larger amounts of soap to foam and clean materials, and (2) hard waters readily precipitate carbonates (known as scale) in piping systems at high temperatures (Dunnivant, 2004). The EDTA titration method for determining the hardness of a water sample will be used.

(b) Total organic carbon

Total Organic Carbon (TOC) is a rapid method that analyses for organic carbon and expresses the result as the amount of carbon found. It is a non-specific method unable to distinguish between various organic species and only indicates that organic carbon compounds are present. The US EPA SW-846 Test Method 9060A for determining total organic carbon will be used.

(c) Other Parameters of Interest

In the course of this research, the following water quality parameters shall be tested and evaluated using established standard procedures of testing: Chemical oxygen demand, Biological oxygen demand, Total nitrogen, Total phosphorus, Total Iron, Sodium, Magnesium, Calcium, Zinc and Sulphates.

6.2.3 *Micro-biological contaminants*

Total coliform and Escherichia Coli (E.coli)

The US EPA Method 1604: Total Coliforms and Escherichia coli in Water by Membrane Filtration Using a Simultaneous Detection Technique (MI Medium) will be used to determine both the total coliform and E.coli. This test method describes a sensitive and differential membrane filter (MF) medium, using MI agar or MI broth, for the simultaneous detection and enumeration of both total coliforms (TC) and Escherichia coli (E. coli) in water samples in 24 hours or less on the basis of their specific enzyme activities.

6.3 Data Analysis

Water quality data often collected at different sites over time usually exhibit the following characteristics: non-normal distribution, presence of outliers, missing values, values below detection limits (censored), and serial dependence. It is essential to apply appropriate statistical methodology when analysing water quality data to draw valid conclusions and hence provide useful advice in water management. Sequel to the laboratory experiments, water quality parameters shall be subjected to descriptive statistics and a one-way analysis of variance (ANOVA) shall be developed to compute the significant difference between sampling points at 95% confidence level. Karl-Pearson correlation coefficient (r) shall be calculated, and correlation for significance shall be evaluated using a t-test. More so, water quality parameters shall be modelled and subjected to trend analyses. Also, correlation matrix shall be conducted to establish relationships between the retention time and quality of the stored water taking cognizance of catchment and storage materials.

6.4 Final report compilation

A draft research report will then be compiled and submitted to the faculty research and publications committee for discussion. The input from the committee will then be incorporated after which the report will be forwarded to the Directorate of Research and Publications for final editing by the mandated editorial body and a final report produced.

6.5 Dissemination of research results

A dissemination workshop will be conducted to share the findings from this research and obtain consensus from a cross section of professionals from industry, colleagues in the faculty, University management and key staff within the university. With support and approval from the Research and Publications Directorate, the research shall be published in an indexed journal, with credit being given to Kabale University.

7.0 ETHICAL ISSUES

7.1 Ethical approval

Approval to conduct this study will be obtained from the Research and Publications Advisory Board (RPAB) which will check whether the research aims and research design are ethically acceptable and whether they conform to the code of conduct of Kabale University.

7.2 Potential for harm

This research does not deal with any potentially harmful material and therefore there is no possible source of harm in terms of pain or injury which can result from any of the study procedures.

7.3 Results communication

The research results will be communicated in an honest, reliable and credible manner. The results will be as transparent as possible. Plagiarism and research misconduct, including making up or falsifying data, manipulating data analyses, and misrepresenting results in the research report will be avoided as much as possible.

8.0 OUTCOMES

The expected outcomes from this research are:

- To check whether the water quality is in compliance with the standards, and hence, suitable or not for the designated use;
- Establish the relationship between retention time and quality of the water;
- Investigate the influence of catchment and storage materials on the quality of the harvested rainwater; and
- To check whether upgradation/change of an existing system is required and to decide what changes should take place.

9.0 EXPECTED DELIVERABLES

The expected deliverables of this research can be linked to the specific objectives as follows:

Specific objective	Deliverables
1. To experimentally evaluate the physical, chemical and bacteriological water quality of the rainwater samples	• Weekly physical, chemical and bacteriological water quality parameters shall be established and evaluated

2. To investigate the level of purity of roof-harvested rainwater from different rooftops and tank materials as compare with the WHO and Uganda drinking water standards	• Suitability analyses of the harvested and stored rainwater shall be established • Recommendations shall be conveyed to the stakeholders for possible implementation
3. To model and establish correlation matrix between retention time and water quality	• Correlation matrix shall be between retention time and water quality parameters. • Statistical analyses shall be conducted to compute the significant difference among the sampling points at 95% confidence level. • Water quality parameters shall be modelled for prediction purposes

10.0 STAFFING

The principal investigator of this research project is Philip Tibenderana, Assistant Lecturer in the Department of Civil Engineering, with both practical and academic experience of in the areas of water resource management. He has acquired extensive knowledge in the area of roof water harvesting and especially in the design and construction of various roof water harvesting technologies, but without putting much emphasis on the water quality issues around the harvested water. With his strong academic background in water resource management, he will guide the team in acquisition of water samples, water quality analysis and preparation of the final research report. He will also participate in organization of the dissemination workshop and spearhead the process leading to publishing of an article from this research in an indexed journal.

The second investigator is Moses Nduhira Twesigye-omwe, Associate Professor of Civil Engineering. He has done extensive research in the various fields of civil engineering especially civil engineering materials, geoenvironmental engineering and water resources engineering. On this project, he will provide guidance and assistance in conducting this research, in addition to supporting the analysis and drawing of relevant conclusions from the research. He will also support the technical compilation of the research report, ensuring that it meets the minimum research standards.

Michael Tobby Agwe, Assistant Lecturer in the Department of Civil Engineering has wide practical and academic experience in environmental engineering. He brings experience from public health engineering perspective of the deterioration of water quality over time and also has a wide range of knowledge in academic research. He will be responsible for ensuring that the research is conducted following fundamental research principles and conclusions drawn are beneficial to the wider body of knowledge.

Taofeeq S. Abdulkadir, Senior Lecturer and visiting scholar in the Department of Civil Engineering, Kabale University, Uganda has extensive experience and has previously published research papers in RWH. With his wealth of experience in research and publication, he will guide the team in the critical analysis and interpretation of the results, design of paper structure and proof reading of the reports emanating from this research.

Denis Byamukama, Teaching Assistant in the Department of Civil Engineering at Kabale University is a graduate student of Civil Engineering at Kampala International University. He has wide experience in fieldwork and the use of harvested rain water in rural communities in various parts of Kigezi Highlands. He is further motivated as a born of these highlands as this research seeks to solve several health issues associated with the use of stored harvested rainwater. He will support the team in arranging all field works and laboratory studies as well discussion of results.

11.0 BUDGET

The total budget of the research, including research ethical approval costs, research materials, laboratory tests, dissemination of research results through a dissemination workshop organized for key stakeholders in academia and industry, and publishing in an indexed journal is estimated at UGX 166,930,000 (One Hundred Sixty Six Million, Nine Hundred and Thirty Thousand Shillings Only) as broken down below.

S. No.	Item	Unit	Quantity	Unit Cost (Shs.)	Amount (Shs.)
1	**Research Ethics approval**	sum			**2,000,000**
2	**Stationery**	sum			**1,200,000**
3	**Research Materials**				
3.1	Internet				120,000
3.2	Procuring Software for data Analysis				1,350,000
	Sub Total research materials				**1,470,000**

4	**Collection of water samples/sampling**				
4.1	Sampling bottles		150	10,000	1,500,000
4.2	Ice	sum			500,000
4.3	Sample box		5	400,000	2,000,000
4.4	Transport to collect samples	mileage	7,200	1,800	12,960,000
	Sub Total collection of water samples				**16,960,000**
5	**Laboratory tests of 170 water samples (5 samples for 30 days = 150 samples plus 20 field and trip blanks for quality assurance) (to be conducted at SWUWS Laboratory)**				
5.1	pH		170	20,000	3,400,000
5.2	Conductivity		170	40,000	6,800,000
5.3	Color		170	20,000	3,400,000
5.4	Taste and odor		170	20,000	3,400,000
5.5	Turbidity		170	40,000	6,800,000
5.6	Suspended matter		170	20,000	3,400,000
5.7	Total hardness		170	60,000	10,200,000
5.8	Total Organic Carbon		170	80,000	13,600,000
5.9	Chemical Oxygen Demand		170	80,000	13,600,000
5.1	Biological Oxygen Demand		170	80,000	13,600,000
5.11	Total Nitrogen		170	40,000	6,800,000
5.12	Total phosphorous		170	40,000	6,800,000
5.13	Total Iron		170	20,000	3,400,000
5.14	Sodium		170	30,000	5,100,000
5.15	Magnesium		170	30,000	5,100,000
5.16	Calcium		170	30,000	5,100,000
5.17	Zinc		170	30,000	5,100,000
5.18	Sulphates		170	40,000	6,800,000
	Sub Total Laboratory Tests				**122,400,000**
6	**Dissemination of research results (100 pple)**				
6.1	Venue (hall hire) incl. PA system	sum			700,000
6.2	Meals	no.	100	30,000	3,000,000
6.3	Transport refund for participants	no.	100	50,000	5,000,000
	Sub Total Dissemination of results				**8,700,000**
7	**Other costs**				
7.1	Research Assistants SDA (5 assistants for 30 days)	days	150	20,000	3,000,000
7.2	Honorarium for investigators	each	5	1,500,000	7,500,000
	Sub Total Other Costs				**10,500,000**
8	**Editorial, printing and binding costs**	sum			**3,000,000**
9	**Final report production**	sum			**700,000**
	TOTAL				**166,930,000**

12.0 WORKPLAN

ACTIVITIES	**Oct-22**	**Nov-22**	**Jan-23**	**Feb-23**	**Mar-23**	**Apr-23**
Literature review	▨	▨	▨			
Research proposal development	▨					
Proposal submission		▨				
Proposal approvals		▨				
Material collection and preparation		▨				
Sample collection			▨	▨	▨	
Laboratory tests			▨	▨	▨	
Data analysis					▨	
Report compilation					▨	
Dissemination of research results						▨
Editing, binding and printing						▨

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