ASSESSMENT OF EFFECTIVENESS OF CHLORINATION AND FREE RESIDUAL CHLORINE DECAY AT POINT OF USE IN REFUGEE SETTLEMENTS IN UGANDA :A CASE OF WEST NILE

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Abstract

Uganda is famous for hosting refugees in Africa and world over. Despite this prominence, providing for the needs of the refugees has come with challenges, water, sanitation and hygiene (WASH) inclusive. Against this backdrop, the purpose of this study was to assess the effectiveness of the chlorination programmes implemented in refugee settlements in Uganda. The intent was on establishing the factors that influence free residual chlorine decay at point of use in the refugee settlements in Uganda. The study was contextualized on West Nile. Three refugee settlements were involved namely Omugo, Imvepi 1 and Pagirinya. Specifically, the study examined physicochemical quality and bacteriological load of drinking water in the three refugee settlements; assessed the efficacy of different types of chlorine disinfection programs used in the refugee settlements; sought to establish the relationship between storage conditions at point of use on residual chlorine and bacteriological load water in refugee settlements in West Nile; and sought to propose strategies for better management of quality of treated water at household level in refugee settlements. Water quality measurements, Questionnaires and interviews were used to collect data.

The study objectives were duly achieved and the major findings were; most of the physico-chemical and biological parameters of water at the source points lay within the permissible ranges of local and international thresholds except E-coli, EC, chlorides and total alkalinity. Therefore, chlorination was necessary to improve the potability of water before consumption by refugee households.

The study also established that centralized chlorination system was applied in all the selected settlements. This occurred at the points of distribution before water was drawn for home use. The Free Residual Chlorine at points of distribution in the three settlements was 0.5mg/L. However, the free residual chlorine deteriorated at point of use leading to recontamination of the water.

The predisposing factors for the rapid decay of the free residual chlorine and the eventual recontamination of the water were related to poor storage conditions including the cleanliness of storage devices or vessels and use of dipping system to draw water from the storage vessels including use of dirty utensils. Besides, poor personal hygiene of the refugees such as long finger nails equally affected the quality of the stored water, as well as the long storage time beyond recommended 24 hours, among others. However, the refugees were optimistic that rigorous awareness creation, increasing the distribution of standpipes (POD) and donating water collection and storage devices would remedy the situation.

This study concluded that water recontamination at household level was a big problem facing the refugees in settlements in West Nile. This has increased vulnerability to waterborne diseases. The study recommended need for active engagement of the refugees for requisite behavioural and attitude changes, among others.

Keywords: *West Nile, Refugees, Uganda, Chlorination, Recontamination, Waterborne diseases, Permissible, Parameters.*

Declaration

I, Dithan Mukiibi, hereby declare that to the best of my knowledge, this piece of work titled ***"Assessment of effectiveness of chlorination and free residual chlorine decay at point of use in refugee settlements in Uganda: the case of West Nile"*** is an original thought in reference to the lecture notes and my experiential knowledge in water and sanitation services in emergency situations. It has never been submitted to this or any other institution of higher learning for any award either in part or full. Where other pieces of work have been used in building arguments and providing debates, due reference has been made thereof.

Dithan Mukiibi (**RM17M45/004**)

(Student)

Signature……………………………………………………… Date………….

Approval

I certify that this dissertation titled ***"Assessment of effectiveness of chlorination and free residual chlorine decay at point of use in refugee settlements in Uganda: The case of West Nile"*** has been duly compiled by Dithan Mukiibi under my guidance and supervision and is now ready for submission and examination.

Mr. Bernard Twinomugisha

(Supervisor)

Signature……………………………………………………… Date ……………………………………

Dedication

To my better half, Mrs.Priscillah Nambaziira Mukiibi, my supervisor Mr. Bernard Twinomugisha, my brother Abel Mutyaba, and Twikirize Wilberforce. I attribute all this success to you. Thank you for providing a reliable bridge on which I cruised to nick this point!

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While I count this as a journey well-travelled, it will be unfair to assume that everything that transpired along the way was a one man's game. Never was it. Several key persons played vital roles that amplified, augmented and lubricated the wheels of the entire research process. In the amplification role, I am greatly indebted to my supervisor, Mr. Bernard Twinomugisha, who oversaw the production of this dissertation right from idea inception stage to the actual completion and submission of the final output to the university. He made sure that every digression that arose from time to time was corrected and addressed while also providing me with leads to the best sources of information materials and how to annotate and paraphrase them so that I produce a dissertation with rigour. I am sure that I am not romanticizing the praises I am heaping you here because even the past dissertations that you have supervised equally heap you with similar endearments. Thank you for playing the role of the best research and dissertation writing coach. I am very proud that I have learnt a lot from you which will keep illuminating my career from time to time especially on occasions when I meet research and report writing related assignments.

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critical areas that affected communities. Not only did you expose us to new knowledge but also, you exposed us to areas that required out immediate attention such as WASH challenges in humanitarian settings. This gave birth to the crafting of a field-based study on decay of free residual chlorine (FRC) the findings of which are presented in this dissertation. On the same footing, I am very grateful to the management of Imvepi I, Pagirinya, and Omugo refugee settlements as well as the refugee households for their supportive role in supporting me for the entire period I camped at their stations to conduct the socio-economic survey and to measure the water quality parameters both onsite and in the laboratory. It was an eliciting activity that I will continue to reminisce about during my career. Thank you so much for treating me as one of your own.

This study was successfully accomplished courtesy of the input of several 'lubricants.' Chief of these were my employers, World Vision Uganda. You are so exceptional that you created a plan for me that enabled me to keep working while I pursued studies. This DNA is what makes you the top-notch and best employer in Uganda. I am very grateful for this gesture and therefore, I credit your for treasuring your employees and respecting the 21st century adage that success, competitiveness and quality services are made possible by human resources because they are inimitable and serve as the veins through which organizational life pulses. I will always credit you for that. In the same capacity, I acknowledge the contribution of my wife, Mrs Priscillah Nambaziira Mukiibi You are a very good example to me and to my circles of how a successful man has a phenomenal and far-sighted woman behind them. Thank you for the unwavering support that not only made my academic journey successful, but by showing me how committed you are to seeing that our sweet young angels follow our footprint by walking along a levelled landscape. Believe me, today, you and I are real victors. Lastly, I have a couple of great people in my cohort at UCU that never settled unless they confirmed that I have duly completed that research process. These are; Mrs. Evaline Nuwasiima and Mr. Matovu Joseph. Thank you for playing the corporate human responsibility role by ensuring that I fulfilled this norm and ready myself for reaping the same dividends as you do from your workplaces since the time when you accomplished this journey. I promise that I will become an active actant in our sociogram so that our network grows further; the old adage goes that “combined efforts break the bone.”

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List of Abbreviations and Acronyms

ANOVA	:	Analysis of Variance
CVI	:	Content Validity Index
DRC	:	Democratic Republic of Congo
FCR	:	Free Chlorine Residual
FRC	:	Free Residual Chlorine
LICs	:	Low Income Countries
POD	:	Point of Distribution
POU	:	Point of Use
SD	:	Sustainable Development
SDGs	:	Sustainable Development Goals
SPSS	:	Statistical Package for Social Sciences
UN	:	United Nations
UNHCR	:	United Nations High Commission for Refugees
UNICEF	:	United Nations Children Fund
WASH	:	Water Sanitation and Hygiene

WHO	:	World Health Organization
WVU	:	World Vision Uganda

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CHAPTER ONE

GENERAL INTRODUCTION

1.0 Introduction

Water is the greatest need for all forms of life on earth. Beyond being a natural resource, water is also an irreplaceable economic resource (Alexandratos et al., 2019; Ngene, 2021). This accounts for why its availability eases man's activities such as agriculture, home consumption, hygiene maintenance and recreation, among others (Duran-Encalada et al., 2017). For this reason, the provision of safe drinking water is an overarching livelihood, sustainability, and public policy issue (Gazzeh & Abubaker, 2018). Further, this importance is supported by the Goal 6 of the 2030 Agenda for Sustainable Development (SD) commonly known as sustainable development goals (SDGs). SDG 6 reaffirms the commitment of members of the United Nations (UN) to achieving universal and equitable access to improved drinking water and sanitation for all by 2030 (Anthonj et al., 2018; Gazzeh & Abubaker, 2018).

In preparation to meet this goal and its targets, several interventions have been taken at both international and national levels and more especially, in the developing countries. However, while these initiatives have been undertaken to increase the availability of safe drinking water, the level of scarcity is reportedly higher. For instance, an estimated 40 percent of 7 billion people are believed to be suffering from consequences of water scarcity (Mulei & Gachengo, 2021). Comparably, this challenge is even greater in rural areas of many low-income countries (LICs) (Martinez-Santos et al., 2020) and yet the global rural population increased by 26 per cent between 1980 and 2020(Carter, 2021).

The most likely group that will bear the brunt of this anticipated shortage are vulnerable populations and more so, those living in humanitarian emergencies such as refugees. This chapter presents background information about water quality challenges in humanitarian emergencies. Contextually, the concern of the study was on interventions undertaken to improve quality of water. More specifically, the focus was on chlorination and the efficacy of chlorination systems applied at points of distribution (POD). Further emphasis was on free residual chlorine (FRC) decay at the points of use (POU). In this study, both Free Chlorine Residual (FCR) and Free Residual Chlorine (FRC) are used interchangeably to convey similar meaning. In the chapter also, the problem statement is stated, the purpose of study is outlined, the study objectives are defined, the research questions to be answered by the study are stated, the scope of the study is defined, the justification of the study is presented and the significance of the study is also charted. The chapter winds with a summary that links this chapter to the next.

1.1 Background

Worldwide, there are 26.4 million refugees (UNHCR, 2021b). This number has increased greatly after February 2022 when Russia invaded Ukraine and the interstate war between Israel and Palestine that started in October 2023. The predisposing factors leading to this burgeoning number of refugees are: the ugly hand of capitalism, perennial armed conflicts, devastating military coups in Africa, Asia and South America, natural disasters or xenophobia (Amaga, 2018). World Health Organization (WHO) (2014) reported that on annual basis, about 2.2 million people die worldwide due to water-borne diseases which are transmitted through the fecal-oral transmission cycle. The most common diseases are Diarrhoea, Cholera, Typhoid fever and Hepatitis A. Of the mentioned diseases, diarrhoea and cholera are the most prevalent and common causes of death. A lack of sustainable access to safe water leads to prevalence of the two waterborne diseases (WHO, 2011b) which on average, claim lives of about 700,000 under five children annually (Anwar et al., 2021). This statistic is even worrying for humanitarian environments such as refugee settlements. For example, Nannyonga et al. (2012) reported that 49% cases of child mortality in these settings were caused by diarrhoea.

As earlier noted, Uganda is an epicentre of refugees in Africa and East Africa respectively. Generally, given the impeding causes of refugee problem in neighbouring countries, it is anticipated that there might even be a high influx of refugees in the coming years and this could result in further overcrowding and scarcity of drinking water consequently resulting into frequent waterborne disease outbreaks. To minimise the vulnerability of refugees and or any population resident in a humanitarian setting, it is important that waterborne disease induced mortalities are circumvented. This is possible when the quality of available water sources is boosted. Such an effort can enable the refugees to use potable water. One way through which this goal can be met is through chemical treatment of the water using chlorine.

Chlorination is the most widely used chemical method for treating water in humanitarian emergencies (Sikder et al., 2020). Chlorination is defined by Safe Water Drinking Foundation (2017) as a chemical disinfection method that uses various types of chlorine or chlorine-containing substances for the oxidation and disinfection of what will be the potable water source. The method was invented in 1744 (Safe Water Drinking Foundation, 2017) and since then, it is widely employed for the disinfection of swimming pool water, wastewater and drinking water systems in different countries (Devi *et al*., 2021; Vargas *et al*., 2021). Chlorination is necessary to prevent epidemics of waterborne disease (Wilson et al., 2019) by inactivating pathogens (Okeke *et al*, 2019). Besides, chlorination produces residuals that are useful for preserving the quality of water in a distribution system (Okeke et al, 2019). The method is commonly used because it is cost effective, easy to use and provides residual protection to microbiological contamination after water collection (Sikder et al., 2020). In settings with refugees, the application of chlorination can either be centralized where bulk water supply tanks are used or decentralized where chlorine is added in water containers at household level, also called point of use (POU) water treatment (Branz *et al*., 2017). Despite the endeavours to disinfect and supply quality water, in humanitarian contexts, free residual chlorine decay is affected by water storage conditions (Wu *et al*, 2021). Uganda might not be an exception.

Uganda is number three refugee hosting country globally and number one in Africa. It has a refugee population of about 1.6 million people (UNHCR, 2024). The biggest number (62%) is constituted of South Sudanese while 29% come from DRC. The rest are from Burundi, Rwanda, Somalia, Eritrea, Ethiopia, Sudan and others. These refugees live in settlements that are located in Western Uganda and West Nile. The settlements are: Oruchinga, Nakivale, Kyaka II, Kyangwali, Bidi Bidi, Omugo, Imvepi 1, Palorinya, Rhino Camp and Pagirinya. The refugees in Uganda face several challenges, shortage of potable water inclusive. Even when they are supplied with chlorinated water, the deterioration of the quality of water at points of use has been reported (Meierhofer et al., 2017). Indeed, cases of contaminated treated drinking water are common (Bwire et al., 2021) and these have led to outbreaks of diarrhoeal diseases such as cholera and dysentery. Out of listed refugee settlements in Uganda, only Pagirinya, Omugo and Imvepi 1 settlements, all in West Nile, were selected for this study. Pagirinya settlement was established in 2016 and hosts 32,000 refugees; Omugo settlement is home to 43,000 refugees from South Sudan (UN Women, 2022) while Imvepi 1 was established in 2017 and currently, it hosts 95,000 refugees although it has a capacity of 110,000 people (Oxfam International, 2022). In the three settlements, there is centralized chlorination of water (World Vision Uganda [WVU], 2020). However, little is known about the efficacy of this method, the water storage conditions at points of use and how the storage conditions affect the decay of free residual chlorine in the water stored and used by the households. This study sought to determine the effect of water storage conditions on the quality of chlorinated water that is drawn from the points of distribution which or sites.

1.2 Problem statement

The increasing numbers of refugees in settlements in West Nile has caused a high demand for potable water. To meet this demand, UNHCR and other partners have established centralized water collection points in the refugee settlements where chlorine is used to disinfect the water before it is drawn by refugees for home use (World Vision Uganda Response Report, 2020). However, much as the supply of safe water to the homesteads in refugee settlements has been increased overtime; the cases of breakout of waterborne diseases are high (Bwire et al., 2021; Refugee Health Report, 2020). While this situation manifests a possibility of recontamination of chlorinated water along the supply chain, the possible linkage has yet been explored and explained. Indeed, although studies (such as Bwire et al., 2021; Mahamud et al., 2012; Steele et al., 2008) have shown that contamination of previously safe chlorinated drinking water among displaced populations in Uganda and attributed it as the likely cause of cholera outbreaks, the relationship between storage conditions and the decay of free residual chlorine has not yet been explored, leading to a knowledge gap. Besides, the contamination of treated water at point of use (POU) is not clearly defined in the guidelines for water treatment in humanitarian settings (such as refugee settlements) (Ali et al., 2015). Moreover, studies elsewhere (such as Gunther et al, 2013; Stocker et al, 2015) are inconclusive on whether household-level storage conditions could be the cause of contamination. Guided by this urgent need, the purpose of the study was to establish the linkage between chlorination methods in the selected settlements, the effect of water storage conditions on free residual chlorine decay and the bacteriological load quality parameters of the water parameters by conducting tests in controlled conditions.

1.3 Objectives

The main objective was to assess the effectiveness of chlorination method of treatment and decay of free residual chlorine at point of use in refugee settlements in West Nile. The intent was to provide insights into the current state of drinking water contamination in the refugee settlements basing on both primary data, review of the available literature and measurements.

1.3.1 Specific objectives

1) To examine the physicochemical quality and bacteriological load of drinking water in refugee settlements in West Nile.
2) To assess the efficacy of the chlorine disinfection programs used in refugee settlements in West Nile.
3) To establish the relationship between storage conditions at point of use on free residual chlorine and bacteriological load of water in refugee settlements in West Nile.
4) To propose strategies for better management of quality of treated water at household level in refugee settlements in Uganda.

1.3.2 Research questions

I. Does the quality of drinking water in refugee settlements in West Nile comply with international and National standards for safe drinking water?

II. What chlorination treatment programs are used in refugee settlements in West Nile and how effective are they in relation to decay of free residual chorine?

III. What is the effect of storage conditions on residual chlorine and bacteriological quality of water in refugee settlements in West Nile?

IV. How can the quality of water best be managed at household level in refugee settlements in Uganda?

1.4 Scope of study

The study was conducted at three sites, Pagirinya in Adjumani District, Omugo in Terego district and Imvepi 1 in Moyo district, all in West Nile region of Uganda. The study examined the point of source physicochemical and bacteriological load of drinking water in the selected refugee settlements; assessed the effectiveness of chlorination method of water treatment in the settlements; and the effect of storage conditions on FRC and bacteriological load of water at POU. The study took a period 6 months.

1.5 Justification

A limited number of studies on water contamination at POU in refugee settlements in Uganda exist and yet frequent outbreaks of waterborne disease have been reported. Thus, there was a knowledge gap on why water borne disease have continued to be a threat to the refugee populations in Uganda and yet the humanitarian organizations that are in charge have invested highly in WASH services while also adhering to SPHERE standards. The Sphere standards are a set of principles and minimum humanitarian standards in four technical areas of humanitarian response (Sphere Association, 2018). The areas are: water supply, sanitation and hygiene promotion (WASH), food security and nutrition, shelter and settlement; and health (Sphere Association, 2018). According to Sphere guidelines, on average, a refugee household requires 20 litres of safe drinking water per day (WHO, 2011). Besides, Sphere (2004) suggests that in emergencies the maximum distance from any household to a water point should be 500 metres while the maximum waiting time to collect water should be 15 minutes (WHO, 2011). However, much as these conditions have been somewhat met in the refugee settlements in West Nile, outbreaks of waterborne diseases have continued to be common. The outbreaks could imply that either the water supplied is contaminated, the treatment system is ineffective or the water was poorly stored at points of use. Therefore, this study was justified by the need to establish what the root cause of the problem could be so that appropriate remedies are suggested. This importance of this study is further justified by the high numbers of refugees in Uganda. The refugee population in Uganda is bigger than total population of countries such as Djibouti (988,000), Comoros (861,901), Montenegro (628,066), Malta (441,531), Iceland (341,243) and Seychelles (98,347) (Worldometer, 2023). The study therefore contributed towards narrowing the information gap on decline in water quality and recontamination at point of use. The study aimed at generating credible empirical information that will be helpful in the formulation of interventions for managing the quality of water for mitigating outbreaks of water borne diseases in refugee settlements in Uganda and beyond.

1.6 Significance

The study findings are important to the following parties;

The anomalies identified by the study may provide a basis for policy makers and planners in the institutions and organizations providing humanitarian assistance to refugee settlements to identify critical areas in the safe water chain that should be addressed in order to prevent diseases induced by human practices surrounding the handling of household drinking water to take corrective actions in form of strategic plans for addressing the loopholes in the management of the water sources.

The study findings are very useful to future scholars interested in carrying out studies in a related field. They could borrow the methodology as well use the study findings as a source of secondary data to enrich their studies. The study findings have also provided documented evidence of the declining quality of water at points of use in refugee settlements in Uganda and elsewhere as there is dearth of academic literature and empirical evidence of on water contamination levels and their implication on human health.

The precarious situation of the refugees in meeting their needs for quality water will be brought to the fore by this study. As a result, their situation should attract several WASH awareness programmes which can improve on their wellbeing and minimize cases of mortality caused by waterborne diseases.

The riddles that the researcher has gone through have the potential of boosting the skillset in reviewing literature, collecting and analyzing data, report writing and presentation which could be applied at a future date. Specifically, the researcher has acquired prowess in handling future research assignments with ease. Equally, after fulfilling the norm of Uganda Christian University to publish the work in a peer reviewed journal, the market value of the researcher could improve as he will be indexed in the reputable research journal databases such as Google Scholar. Last, the accomplishment of the study has enabled the researcher to fulfil the norm of meeting the academic requirements for the award of the degree of Master of Science in Water Engineering and Sanitation of Uganda Christian University, Mukono.

1.7 Conclusion

Chlorination programmes in refugee settings cannot guarantee quality of water used at household level in the refugee settings. However efficacious the water disinfection programmes are, without any corresponding efforts to ensure that refugee households adhere to the storage and water hygiene guidelines, the chances of recontamination of the chlorinated water are high. Eventually, the population becomes more vulnerable to outbreaks of waterborne diseases. Against this backdrop, the next chapter is devoted to reviewing literature that is related to physicochemical quality and bacteriological load of water in humanitarian settings, the efficacy of chlorination programmes in humanitarian settings, the relationship between storage conditions at points of use, free residual chlorine decay and bacteriological load of water; and the strategies for improving the quality of chlorinated water at points of use in the humanitarian settings.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Globally, adequacy and right quantity and quality of water supply is an indispensable need (Onyutha *et al*, 2022; Vargas *et al*., 2021). Water is physiological need and a determinant of human health either directly when consumed, used to prepare food or indirectly through supporting different activities which sustain human life such as agriculture and industrial development. That is why SDG 3 about good health and well-being and SGD 6 about clean water and sanitation are directly concerned with ensuring that there is adequate water of recommended quality (Alim *et al*., 2020). Despite these commitments, providing universal access to safely managed drinking water by 2030 is still highly contested and might not be realized as was anticipated in 2015 (Lindmark et al., 2022). For example, much as 5–10 litres of water are required per person per day, about 20 % of the world population continue to grapple with no or limited access to clean drinking water (Alim et al., 2020). Basing on the facts and figures above, literature related to scarcity of quality water in humanitarian settings, physicochemical properties of the water, bacteriological load of the water, chlorination approaches applied, water storage conditions at the point of use and its effect on free residual chlorine decay; and strategies for better management of chlorinated water at points of use is reviewed.

2.2 Physicochemical Quality and Bacteriological load of water in humanitarian settings

Worst of all, the SPHERE handbook (2018) recommends that in a refugee setting, each person, on a daily basis requires a minimum of about 15 litres of water. With this factor in mind therefore, Wu and Dorea (2021) argue that both the quantity and quality factors should be borne in mind while planning water supply for refugee settings. Incidentally, this standard has not been met in most humanitarian settings. The cases of insufficient quantity and quality of water for consumption and hygiene are a common challenge as manifested by a high rate of diarrheal disease outbreaks (Sphere, 2018; Wu & Dorea, 2021).

To meet the needs of refugees and other victims of humanitarian crises, the commonly used intervention is to kill or remove the pathogens (Chaukura et al., 2020; Ghernaout & Elboughdiri, 2020). The water is disinfected to ensure that it meets the potability standards (Belmino da Silva et al., 2022; Srivastav et al., 2020). When done, the potential risks associated with exposure to waterborne diseases are mitigated (Maqbool et al., 2021). Disinfection means killing of pathogenic organisms (e.g. bacteria and its spores, viruses, protozoa and their cysts, worms, and larvae) present in water to make it potable for other domestic works (Ghernaout *et al*, 2020; Srivastav *et al.*, 2020). Several disinfection methods are applied in humanitarian emergencies including boiling, chlorination and ultraviolet disinfection (Wu et al, 2021). Disinfectants play a big role in inactivation of the pathogens (Srivastav et al., 2020). In general, chemical oxidants, chlorine, chloramines, chlorine dioxide, and ozone are the most commonly used disinfects (Chaukura et al., 2020). The most preferred among this range, is chlorine is the most used in water disinfection (Chaukura et al., 2020; Costa et al., 2021).

2.3 Water chlorination programmes in humanitarian settings

Chlorination has a long history that dates back to the 19th century (Belmino da Silva et al., 2022). Its notable advantages include: easy to obtain, easy to verify, effectiveness in inactivating most bacterial and viral pathogens; and has a residual protective effect in the water during transportation and storage (Wu et al, 2020). Use of chlorine as a method along the water supply chain is flexible and therefore, it can be applied at the point of source, point of delivery, point of collection or point of use (Wu et al., 2021).

Chlorination has a wide application in disinfection swimming pool water, wastewater and drinking water systems in many different countries (Devi et al., 2021; Vargas et al., 2021). Thus, chlorination is recommended as a solution for preventing the outbreak of waterborne diseases (Wilson et al., 2019). When effectively applied, chlorination makes pathogenic organisms inactive (Okeke et al., 2019). It is also important to note that, chlorination produces a residual presence that maintains quality of water at both the distribution and storage points (Okeke et al., 2019). Free (breakpoint) method is the commonly used chlorination method to disinfect water in humanitarian settings (Wu et al., 2021).

There are different ways of applying chlorine to disinfect contaminated water. The chemical can be applied in powder form (Sodium dichloroisocyanurate [NaDCC] and calcium hypochlorite), as a liquid (bleach solution) or as a tablet (NaDCC tablet) (Wu et al., 2021; Vargas et al., 2021). The solid or tablets are the most commonly used method of application. Compared to powder and liquid forms, chlorine tablets are readily and locally available (Branz et al., 2017; Vargas et al., 2021). The factors accounting for preference of chlorine over other oxidants include its cheap in cost, potency in producing larger volumes of chlorine oxide and germicidal efficacy against most pathogens (Chaukura et al., 2020; Srivastav et al., 2020).

2.4 Relationship between storage conditions chlorinated water in humanitarian settings and free residual chlorine decay

The application of chlorine in water adds a persistent residual matter at the point of distribution and point of use (Maqbool et al., 2021). The residual matter is what is known as free residual chlorine (FRC) (Ali et al., 2021). FRC levels in chlorinated water supplies are supposed to range between 0.2–0.5 mg/L at the point of distribution and point of use. The residual matter also inhibits re-growth of microorganisms in bulk water and on the walls of water pipes (secondary disinfection) (Costa et al., 2021; Fisher et al., 2019; Maqbool et al., 2021). However, in humanitarian settings, this standard as well as recommended turbidity of less than 5 NTU are rarely met because households do not follow the recommended guidelines of storing the water for less than 24 hours (Ali et al., 2021). Therefore, the chlorination process is unlikely to provide sufficient residual protection for the water used by households in these settings. Apart from the failure to follow the guidelines, still, in refugee households, the storage conditions for the chlorinated water might not be conducive to sustain the potency of FRC (Wu et al, 2021). Thus, in most refugee settings, pathogenic re-contamination of water occurs at the point of use (Ali et al., 2021). A study by Sikder *et al.* (2020) in

Bangladesh established that free residual chlorine never kept the chlorinated water in good condition. A similar observation was reported in South Sudan (Ali et al., 2021).

One of the conditions at the point of use that accounts for the decline in the quality of chlorinated water is the mechanism used to draw water for use from the storage vessels. According to Wu et al. (2021), some of the mechanisms used in drawing water from storage devices lead to recontamination of the water. As a result, the efficacy of free chlorine residual is lost. This relationship was proven by a study from northern coastal Ecuador by Levy et al. (2008) and McClain et al. (2017). Results of their studies showed that the method of drawing drinking water from the storage containers, location and height of storage containers and presence or absence of taps on water storage containers affected the quality of chlorinated water.

Elsewhere, a study done In Kakamega in Western Kenya by Kioko et al. (2012) established that 33% of the households used a bucket, 26% a container with a narrow neck, 35% a clay pot and 6% a bottle for storing chlorinated water. Their study observed that the type of vessel used to store drinking water affected the safety of the water in such a way that when a household used wide-mouthed containers like buckets and pots which accounted for 68% of the entire sample, the stored water was more prone to contamination because of the large open surface area of the storage vessels. Not only were the buckets and pots open, but also, the users often dipped cups and jugs to draw the water from storage vessels or devices, which increased the magnitude of recontamination by dirty hands and dirty containers. This observation is not surprising because in most refugee camps, people will use containers they already own or containers that they are availed with when they reach a new location. The containers can either be narrow-necked or wide-necked in structure (Akhter *et al.*, 2020). Chlorinated water in wide-necked containers is prone to recontamination (Mattioli *et al.*, 2013; Packiyam *et al.*, 2016; Pickering *et al.*, 2010) . To minimise the possibility of recontamination, households are advised to keep the containers covered so that the contact between the water and the outside environmental contaminants is minimised. According to Sheikhi et al. (2014), free residual chlorine dissociates easily when the treated water is stored in containers that have no lids or protective covering.

Studies carried out in many countries such as Malawi, Bolivia and Tanzania have shown recontamination safe drinking water occurs at household storage (Cassivi *et al.*, 2021; Mattioli *et al.*, 2013; Rufener *et al.*, 2010). In Malawi and Bolivia, it was established by Cassivi *et al.* (2021) and Rufener *et al.* (2010) respectively that the method of accessing household drinking water contributed to introduction of pathogens in the stored water. In Bolivia, Rufener and colleagues reported that dirty hands were responsible for recontamination of stored water. Similarly, this finding was reported by Mattioli *et al.* (2013) in Tanzania where households with members having dirty hands such as untrimmed fingernails suffered from diarrheal diseases. The dirty hands provided a pathway for enteric bacteria and viruses the stored water, leading to outbreaks of diarrheal illnesses. In comparison, a study by Mugumya et al. (2020) in Kolladiba town, Ethiopia reported that 55.9% of respondents accessed drinking water from storage vessels by pouring. Pouring by tilting the vessel or by use of a clean, special utensil are the safest methods of drawing drinking water from containers for use (Mugumya *et al.*, 2020). Thus, the use of this method minimised the incidence of recontamination and therefore, a low incidence of diarrheal diseases in Ethiopia compared to Tanzania, Malawi and Bolivia.

The decay of free residual chlorine is also affected by environmental conditions such as pH, temperature and mineralogical composition of water (Vargas et al., 2021). For instance, the pH of water influences chemical reactions of chlorine with other chemical compounds (Wu et al, 2021) while the chlorine decay rate is determined by temperature and typically increases with rising temperature (Branz et al., 2017). With regard to mineralogical composition, the presence of chemical contaminants such as nitrates and phosphates also makes water disinfection complex (Vargas et al., 2021) while water with high iron concentrations, ammonia and nitrogen compounds cause a strong chlorine smell (Vargas et al., 2021). The mixing of chlorine and ammonia for example, leads to the formation of chloramines and these have a bad effect on the smell of water (Hassan, 2020; Wang et al., 2018).

In humanitarian settings, there are no standard containers used and this increases the need for chlorinating the water to mitigate any possible recontamination by the storage containers (Wu *et al.*, 2021). Also, most emergency settings as is the case in Uganda, are established in arid and semi-arid areas and therefore the relatively elevated temperatures and intense sunlight exposure lead to losses of free residual chlorine through evaporation and dissociation (Besic et al., 2017; Garcia-Avila et al., 2020). The choice of these ecological environments is attributed to the availability of adequate space since the native people tend to desist from establishing homesteads there because of the harsh climatic conditions such as high desiccation and scarcity of groundwater sources.

2.5 Strategies for improving water quality storage and use at points of use

Several studies (such as De Santi et al., 2022; De Santi et al., 2021; Sikder et al., 2018; Skidder et al., 2020; Wu et al., 2022) have shown that the storage and use of chlorine treated water can greatly be improved upon among households in humanitarian settings. For example, Sikder et al. (2020) noted that authorities in humanitarian settings should endeavour to establish a management team of all WASH implementation partners. Besides, there is also need to ensure that sufficient water quantity is delivered, continuous monitoring to ensure recommended FRC levels at distribution points, and emphasis on awareness creation among the users for complete behaviour change. When there is behaviour change communication, the dynamics of water storage management at household level improve greatly (Rahman et al., 2022; Sikder et al., 2020; Yates et al., 2018).

The laxity in ensuring safe storage of chlorinated water by households in refugee settings is at times influenced by the attitude of the refugees. According to Alam et al. (2020), refugees are open to using other methods of water treatment rather than chlorine. Such methods include boiling and solar disinfection (Center for Disease Control and Prevention [CDC], 2022). With boiling, water is heated to kill disease-causing germs, including viruses, bacteria, and parasites while solar disinfection is a method of using heat and UV radiation to kill bacteria and parasites in water. Solar disinfection works by placing contaminated water in a transparent container and exposing it to strong sunlight for 6 to 8 hours if sunny, or 2 days (if cloudy) (CDC, 2022). This method is most appropriate when water is clear and clean, transparent containers for treatment are available (CDC, 2022). These treatment methods are perceived to be easy to use and were considered more beneficial than chlorine. However, they are not effective and can expose the population to bouts of diarrheal disease outbreaks. Based on this observation, Alam et al. (2020) recommended need for involving community and religious-leaders in formulating and delivering messages that addressed water taste and smell of the treated water so that any mistrust and allayed fears are identified and addressed to maximize the willingness of the refugees to adopt safe water management practices post treatment.

A study in Kenya by Ondieki et al. (2021) found out that even when the refugee settings have better storage containers to increase on use of quality water, at times, the chlorine applied at the treatment points at POU may not be adequate to guarantee the efficiency of FCR. Thus, the internationally allowed minimum chlorine residue of 0.2 ppm at the household and community taps can be achieved and realized when adequate quantities of chlorine dose are applied throughout the water supply system (Ondieki et al., 2021). Using the context of Bangladesh, Faruque *et al*. (2022) suggested that in any humanitarian situation, the humanitarian agencies should be actively engaged and involved in the regular monitoring of drinking water sources. In particular, the monitoring should be strengthened particularly for free residual chlorine levels at points of use. Faruque et al. (2022) equally proffered that there is a great need for monitoring of water quality at household level and where any anomalies have been detected, immediate remedial actions should be explored. Case examples can include regular provision of soap to households in order to improve on use of water with non-contaminated hands. Another plausible strategy would be provision of storage containers with covers and sensitization of users about regular cleaning of the storage devices to mitigate the impact of dirty linings on the chlorinated water.

2.6 Conclusion

The foregoing literature has shown that chlorination is the widely used disinfection method to ensure that households can access and use quality drinking water. Equally, the findings reported by the reviewed studies have shown that chlorinated water can easily be contaminated at points of use. Despite this linkage however, the works of other scholars cited leave contextual gaps (were carried out in other humanitarian settings other than West Nile in Uganda) and methodological gaps (some studies were review papers and so, they lack empiricism). To fill the gaps, data on Pagirinya, Omugo and Imvepi 1 were collected following a methodological protocol charted in the next chapter.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

Water quality measurements and socio-economic data were collected. A detailed account of the procedures followed in collecting and analysing these data to answer the study's research questions is provided. This includes the procedures that were observed in drawing samples and the steps followed in conducting the measurements. As well, the considerations made in recruiting participants to the socio-economic survey are also described while efforts taken to ensure collection of quality and bias-free data are also enumerated. the analytical procedures and pattern followed and rationale for selecting and using them to report the findings are also exposited.

3.1 Research design

The study adopted a mixed methods research design. The design involves mixing and matching quantitative and qualitative methods (Kumar, 2018; Schoonenboom et al., 2017). In this study, the quantitative research design adopted was descriptive. Descriptive data were obtained from a socio-economic survey while the measurements for water quality were obtained through field and laboratory analyses. Water quality monitoring parameters for drinking water sources by international and local sources were applied. Water samples were collected following standard procedures for water quality sampling recommended by the United States Environmental Protection Agency (USEPA)(2015) and Government of Western Australia (2015). The qualitative strand involved collecting and analysing narrative or textual data. Textual data were collected from existing WASH documents about the selected refugee settlements and from interviews that were administered to WASH officers.

3.2 Study Population

The study was limited to household heads in Pagirinya, Omugo and Imvepi 1 refugee settlements (See Table 3.1). Because of the enormous numbers of households, the study largely targeted households that were distant from the points of distribution. These were targeted because the chances were higher that they stored water for long periods of time compared to the households that were located next to the points of distribution.

3.3 Sample size and sampling techniques

The sample size involved in the study and the sampling techniques adopted are discussed below;

3.3.1 Sample Size for socio-economic survey

The sample sizes were calculated basing on Yamane's (1967) formula for determining sample size from a given population. The refugees in the settlements are registered by the commandants. Therefore, it was easy to determine the numbers of households in each zone, with preference made to the zones that were located far away from the central water distribution points (See Table 3.1).

The following formula was used;

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\mathbf{1}+\boldsymbol{N}(\boldsymbol{e})^{2}} \text{.. (Equation 1)}$$

Where;

n= sample size required,

N = number of households,

e = allowable error (%).

For Pagirinya, $n = \frac{211}{1+211(0.05)^2}$=137

For Omugo, $n = \frac{237}{1+237(0.05)^2}$=148

For Imvepi, $n = \frac{165}{1+165(0.05)^2}$=116

Table 3. 1: shows the targeted samples per refugee settlement

Refugee settlement	Households	Sample size
Pagirinya	211*	134
Omugo	237*	148
Imvepi 1	165*	116
Key Informants	8	8
Total	621	409

*There are proportionately big numbers of households in each settlement. Selection of sections of the settlement focused on those located far away from point of distribution as this had an impact on water storage duration.

3.3.2 Sampling techniques

The study adopted both probabilistic and non-probabilistic sampling strategies. For probabilistic sampling, both simple and stratified random sampling techniques were used concurrently. In this study, zones formed strata. Within each zone, still, to accord all the subjects, equal chances of participating in this study, simple random sampling was applied. Simple random sampling involved use of the lottery method. For non-probability sampling, purposive sampling was applied in selecting WASH officers. Theis is because the WASH officers from different agencies working with refugees ordinarily had key information to share that added value on the study.

3.4 Data collection methods and instruments

3.4.1 Data sources

Primary and secondary data were collected using direct observation, Household surveys, face-to-face interviews with key informants and water quality analyses *in situ* and *ex situ*. A transmittal letter from UCU was used to seek permission from the Local Council Officials and the refugee settlement commandants to carry out *in situ* water quality measurements as well as collection of socio-economic data. Secondary data on WASH situation in the respective refugee settlements were also collected by this study. The data were mined from government publications, internal records and reports from humanitarian agencies that support refugees in West Nile such as UNHCR and World Vision.

3.4.2 Data collection methods and Instruments

The data collection methods and instruments used in the study are discussed objective by objective as shown below;

3.4.2.1 Objective 1: To examine the physicochemical quality and bacteriological load of drinking water

To achieve this objective, the research sought for answers to the following question: Does the quality of drinking water comply with the international and National drinking water standards? This was achieved by collecting samples for water quality analysis from points of source.

3.4.2.1.1 Collection for samples for physicochemical analysis

In field, pH, temperature and conductivity were measured using Hach Pocket Pro+ Multi 2 Tester while turbidity was measured using the Turbidity meter model TU-2016 (Table 3.2). The water samples for other physico-chemical analyses in the laboratory were collected directly into clean 1 l aseptic plastic bottles. The plastic bottles were sterilized in an autoclave. The steam sterilization of the bottles was conducted at 120 degrees centigrade for 20 minutes following the recommendations of Water, Engineering and Development Centre (WEDC), Loughborough University (WEDC, 2017). Water samples for metal analyses were collected into 100 ml plastic bottles and nitric acid (HNO_3) was added to the samples to bring the pH down to 2 for the metals to remain in solution following the recommendations of the United States Environmental Protection Agency (USEPA, 2015). All samples for chemical and metal analyses were stored in an ice chest and transported to National Water and Sanitation Laboratory in Arua City for analyses.

Table 3. 2: Instrumentation for physicochemical parameters of water.

Parameter	Protocol	Instrument
pH	Instrumental, analyzed on site	Hach Pocket Pro+ Multi 2 Tester
Temperature	Instrumental, analyzed on site	Hach Pocket Pro+ Multi 2 Tester
Conductivity	Instrumental, analyzed on site	Hach Pocket Pro+ Multi 2 Tester
Turbidity	Nephelometric method, analyzed on site	Turbidity meter model TU-2016.

3.4.2.1.2 Bacteriological load

The bacteriological quality of water was determined using Membrane Filtration technique for Total coliforms and *E.coli* (ISO 9308-1:1990) because it gives a direct count of total coliforms and fecal coliforms present in a given sample of water. Petrifilm was used™ to determine the total coliforms in the water samples. The 3M Petrifilm RAC Plate is a culture medium that is sample-ready out of the package. The 3M Petrifilm RAC Plate includes nutrients required for the enumeration of aerobic bacteria from samples. Also, the Petrifilm RAC Plate has a cold-water-soluble gelling agent and a dual-sensing indicator technology. After lifting the top film, the sample is first added to the center of the 3M Petrifilm RAC Plate, and then the top film is released. A flat plastic sample spreader is placed on the closed, inoculated plate, and then the sample is spread over the plate using light pressure on the spreader. The plate is allowed to sit for 1 minute. During this process, the gelling agent is allowed to solidify (Lingle et al., 2022). The nutrients contained in the plate allow for aerobic bacteria growth when plates are incubated at the correct temperature of 35°C ± 1°C . The combination of the nutrient, gelling agent and dual-sensing indicators eases colony enumeration in a period of about 24 hours (Lingle et al., 2022). 3M Petrifilm was preferred against the other standard methods such as membrane filtration, MPN, or chromogenic media methods which are ideal for testing the total coliform and E. coli, because of limitations in the field, this method is the easiest, simplest and effective as it does not need any additional equipment. This method has been used by other researchers (Hyder et al., 2022; Lingle et al., 2022; Pearson et al., 2008; Pichel et al., 2023; Schumacher et al., 2022; Schraft & Watterworth, 2005) and has produced very good results.

3.4.2.2 Objective 2: To assess the efficacy of chlorine disinfection programs used in refugee settlements.

To achieve the objective 2, the question of "what are the chlorination programs of drinking water treatment that are used in refugee settlements", had to be answered. Data on the chlorination programs were collected through review of documents and literature, key informant interviews with WASH officers using an Interview guide, direct observation using an observation checklist. Document analysis followed READ Approach proposed by Dalglish et al. (2020). READ connotes Readying documents, Extracting or mining key data, Analyzing the mined data and distilling or presenting the information as findings. Interviews lasted for 60 minutes and were audiotaped for thoroughness. For observation, notes and photographs were equally be taken. Some of the photographs were incorporated to illustrate the findings in Chapter Four.

3.4.2.3 Objective 3: To establish the effect of storage conditions on residual chlorine decay and bacteriological load of water

This study sought to provide answers to the following question; Do the storage conditions of chlorine treated water affect free residual chlorine decay leading to the recontamination of water? To achieve this objective, measurements on water quality parameters were taken alongside a socio-economic survey of the households to establish the status of water storage conditions at household level.

3.4.2.3.1 Bacteriological load of water

The comprehensive Wagtech portable water testing kit was used in the study to measure the fecal coliform counts and free residual chlorine. The testing kit used in this study was WAGWE10030 – Wagtech Potatestþ. The kit was used because it is recommended by WHO especially when it is fit for use in remote areas. The water samples were drawn using the same devices that the refugees used for drawing water and poured in the de-ionized 100 mL sample bottles. The sample bottles were rinsed 3 times with the stored water. The bottles were covered tightly with bottle tops and labelled with a code that was assigned to each household during the socio-economic survey. The sampling time was equally recorded on each bottle. All samples were stored in a small cold box with ice packs immediately after collection until tested within 6 hours of collection. The samples were filtered using 0.45 mm pore size, 47 mm diameter filter membrane and incubated the loaded petri-dish rack at 44 C for 14 hours following 1 to 4 hours resuscitation at 35^{0}C. This was followed by a systematic inspection of the plates for growth of fecal coliforms, column by column in the grid. The last step involved counting of all the yellow colonies irrespective of colony size using a hand lens within a few minutes, as the colours are likely to change on cooling and standing. The values were recorded as number of fecal (thermo-tolerant) coliforms or CFU per 100 mL of water.

3.4.3.2 Free residual chlorine decay test

Free residual chlorine was tested using the Wagtechpotatestþ Kit. This involved using diethyl-phenylene diamine (DPD) reagent. DPD tablet was used. One DPD1 tablet was added into each test tube, followed by filling it with water samples that were drawn from the refugee households to the 10 mL mark. This step was followed by vigorous shaking of the test tube in order to allow free chlorine to react with DPD to produce coloration. The intensity of the pink colour was proportional to free residual chlorine concentration. The color intensities were measured by comparing them against color standards using a Wagtech Comparator. The disk reading represented the free chlorine residual as milligrams per litre.

3.4.2.4 Objective 4: To propose best practices for management of quality of water at point of use in refugee settlements

This objective was to provide answer the following questions; How can the storage conditions of water and its use be improved to mitigate contamination? To achieve this objective socio-economic survey of the households using a pre-tested semi-structured questionnaire was administered. Interviewing of WASH officers using an interview guide was also done. The survey questionnaire (Appendix A) and the interview guide

(Appendix B) were vetted for applicability and simplicity by the Research Ethics Committee of UCU.

3.5 Data quality Control

3.5.1 Field and Laboratory water quality measurements

All field equipment(s) were calibrated according to their standard operation procedures before use while water sample containers were sterilized in an autoclave for 20 minutes at 120^0C (WEDC, 2017). Care was taken to prevent accidental contamination of samples during their collection and transportation to the laboratory. Precautions were taken to ensure that those who receive the samples produced valid results. For effectiveness, the samples were analysed in triplicate. This was intended to minimize errors and avoid misleading results and recontamination. Also, the competences of analysts were also assessed to ensure that quality results were reported. As well, a pilot visit was made to the Arua Analytical Laboratory of NW&SC to ensure that it had established and documented analytical methods, equipment calibration procedures, management lines of responsibility, systems for data retrieval, and sample handling procedures.

3.5.2 Socio-economic survey

Data quality for the socio-economic data involved two levels; establishing the validity and reliability of the questionnaires for quantitative data and ensuring the reliability and rigor of the interview data. The entire process is discussed below;

3.5.2.1 Validity

Validity is conceived by Binti (2020) to mean the truthfulness of the research instruments. There are several types of validity including criterion, content, construct and face. Two of the types listed, face and content will be ensured by this study. Kumar (2018) advises that face validity is important in research because it ensures that the statements and questions used to collect data are tapping the understanding of the respondents in both absolute and relative terms. On the other hand, content validity is concerned with ensuring adequate coverage of the dimensions measuring the study variables (Odiya, 2009). Basing on the above connotations, Binti (2020) recommends that a seasoned researcher should ensure that the two forms of validity are duly ensured for credible study findings to be realized. In this study, face validity was ensured by submitting the research tool (questionnaire) to my supervisor. This was followed by pre-testing the survey questionnaire on a sample of 20 refugee households at Rwamwanja Refugee Settlement in Kyegegwa District in Western Uganda. This helped the researcher to eliminate unnecessary rubric. For content validity, the below formula was used (Bastilha et al., 2021).

$$CVI=\frac{Number of Questions judged relevant}{Total number of questions judged}$$ ....Equation 2

The CVI for the entire questionnaire was 0.833. The index was high above 0.7 threshold implying that the questionnaire was valid.

3.5.2.2 Reliability

Reliability means the ease with which a research tool can generate results that are consistent as long as more or less the same targeted respondents are engaged in that new setting. The most common method used to establish the reliability of findings is by using Cronbach Coefficient Test (Koonin, 2014). This is available in Statistical Package for Social Sciences (SPSS). According to Randrianarivony et al. (2020), the values obtained should be above 0.7 to suggest reliability of each questionnaire section or otherwise for values below this threshold. The average Cronbach alpha value computed was 0.89. This implied that the entire questionnaire contained reliable statements that would yield more or less related results when administered in a similar setting.

3.5.2.3 Reliability and rigor of interviews

The proposed study involved interviews and yet according to Rutakumwa *et al.* (2020), interviews are associated with biased data. Interviews are normally laden with bias which largely results from the fact that the researcher is considered as the ‘instrument’ by the respondents (Jones *et al,* 2021). Besides, interviews are affected by researcher bias, reactivity bias and respondent bias all leading to biased and subjective responses (Kriukow, 2020). The validity of interview data was ensured through member checks and respondent validation. Following the prescriptions of Coleman (2020), member checks involved echoing, paraphrasing and seeking further clarifications on aspects that seemed ambiguous. Regarding response validation, after transcribing the data, the researcher shared the outcomes with the respondents for purposes of ascertaining that the themes derived and the meanings assigned to the submissions that have been transcribed were reflecting their opinions.

Interview data were equally strengthened using an audit trail. According to Coleman (2020), a detailed account of how the interview sample was selected provides readers with confidence that the results are bias-free. Coleman (2020) collectively calls this process, an audit trail. In this study, a detailed description of all the stages right from selection of the respondents to data collection and analysis was discussed explicitly.

3.6 Procedure for data collection

The researcher sought for a letter of introduction from UCU. This was presented to the settlement commandants obtain assent to carry out the study in the sites. Data on water quality parameters were collected in phases given that three sites were targeted for collection of samples. All the samples were collected and analysed in a period of 3 months. For socio-economic survey, the interviews and administered questionnaires were administered in a space of 27 days.

3.7 Strategy for data processing and analysis

Quantitative data from questionnaires were analysed using descriptive statistics. Percentages, mean and standard deviation were used to present data about the strategies for better management of the quality of water at point of use. Besides, bivariate and multivariate analyses were performed in assessing the factors at household level that caused the fast decay of free residual chlorine. Partial Least Square (PLS) regression was used.

Data from water quality measurements were also analysed using Mann–Whitney U test while parameters on water storage and handling conditions were analysed using multiple logistic regression. This was largely used to evaluate the relationship between presence of fecal coliform bacteria and free residual chlorine in drinking water at source and in storage vessels. The P value 0.05 with 95% confidence intervals was taken as a cut-off point of statistical significance.

The following considerations of World Health Organization were borne in mind for fecal coliform contamination and free residual chlorine. For fecal contamination, a water sample with <1 CFU/100 mL was considered to be uncontaminated while one with 1 CFU/100 mL was considered to be otherwise. The fecal coliform count contamination levels in the drinking water samples were categorized into 0 (none), 1–10 (low risk), 11–100 (moderate risk) and >100 CFU per 100 mL (high risk) basing on the WHO guidelines. The arithmetic mean count for sub-sets of the contaminated samples are reported in the next chapter.

For free residual chlorine, the thresholds used to group the observations into classes were selected based on groupings used in WATA-Standard (WHO, 2019) as follows; FRC between 0 mg/L and 0.2 mg/L was considered high risk since they have insufficient FRC to prevent recontamination; FRC between 0.2 mg/L and 0.5 mg/L–was considered moderate risk and is sufficient to prevent recontamination under normal circumstances, though it may be insufficient during a waterborne illness outbreak or when conditions favour recontamination; FRC between 0.5 mg/L and 1.0 mg/L–was considered low risk and can prevent recontamination during outbreaks of waterborne illness; and FRC above 1.0 mg/L– was considered very low risk as this is above even the range recommended during outbreaks of waterborne illness. If recontamination occurs with FRC above 1.0 mg/L, there may be factors other than insufficient chlorine residual driving recontamination.

3.8 Conclusion

Data on water quality measurements and socio-demographic characteristics of the respondents were generated by the study using the different methods discussed in the foregoing sections. In the next chapter, the data are analysed, interpreted and discussed.

CHAPTER FOUR

PRESENTATION AND DISCUSSION OF RESULTS

4.1 Introduction

The parameters of physicochemical properties of water, bacteriological load and free residual chlorine decay were assessed by the study. The physicochemical parameters and bacteriological load were assessed at point sources. At points of distribution, the free residual chlorine was assessed while at points of use, both free residual chlorine concentration and bacteriological load of water were assessed. Variations in the above parameters were observed in the study setting. The factors accounting for this variation were confirmed through a socioeconomic survey and review of existing related documents. In this chapter, the emerging results are presented and the factors accounting for this difference are analysed and discussed.

4.2 Response rate

The response rate was computed for this study and included in this chapter. Much as the study was carried out in a refugee setting where submission of the households to interviews and other communication and research engagement related activities are highly prioritized by the overseers, it is imperative to note that the refugees are not a captive population where an 100% response rate would be expected. The study had targeted 401 respondents. However, only 324 were accessed and fully engaged in the socio-economic survey. Thus, the response rate was 81% (324/401*100) for survey questionnaires. While eight (8) key informants were targeted by the study, only 6 were accessed. This gave rise to an interview response rate of 75%. The results is presented in Table 4.1;

Table 4.1: Response rates by category of respondent

Respondent category	Settlements			Total	Response rate
	Pagirinya	Omugo	Imvepi 1		
Targeted Household heads	134	148	116	401	324/401*100 =80.7% ≈ 81%
Accessed Households heads	120	131	73	324	
Targeted Key informants	3	3	2	8	6/8*100 =75%
Accessed Key informants	2	2	2	6	

Source: Computed from Calculated Sample Sizes in Table 3.1

As shown in Table 4.1, the response rates were high at 81% and 75% respectively. The result shows that findings from this are credible and representative of the entire sample targeted. This assertion is amplified by the views various writers such as Morton et al. (2012), and Krishnan et al (2016), that studies with a much lower response below 50% of the sample are often less accurate compared to those with a much higher response rate, say 70% and above. Thus, responses received are representative of the population and therefore, the findings are reflective of the opinions of the majority of the key stakeholders. It is indicative that the participants are interested in the study especially when it is investigating matters of critical importance and indeed, in humanitarian and emergency settings such as refugee settlements in Uganda, accessing potable water is one of the physiological of basic needs for the households.

4.3 Socio – demographic characteristics of the respondents

Questionnaires were administered to 324 respondents. The researcher assessed the respondents' gender, age, highest level of education attained, occupation, household size and marital status as proxy indicators likely to influence sanitation and hygiene. The following results were obtained;

Table 4.2: Socio-demographic characteristics of the respondents

Characteristics	Percentage
Gender	
Male	31.5
Female	68.5
Level of education attained	
Never went to school	9.9
Some Primary	18.8
Completed primary	22.2
Some secondary	33
Completed secondary	7.7
Post-secondary	8.3
Age-group	
20 years and below	21.9
21-30 years	31.8
31-40 years	36.4
41-50 years	3.7
> 51 years	6.2
Household size	
<3 members	9
3-5 members	59
>5 members	32

As shown in Table 4.2, majority of the respondents, were female (68.5%). The high number of female respondents in this study can also be linked the gender division of labour in the host communities and even in the ancestral homes of the refugees where domestic chores such as fetching water are a preserve of women at times assisted by their children. Despite the gender imbalance, the study findings captured the views and opinions of both male and female respondents which shows that both categories of gender were interested in the study given that the critical need for drinking water.

Table 4.2 equally shows that most respondents had attended secondary school education though they never completed the level. A reasonable proportion (22.2%)) of the respondents had completed primary education and were able to read and write. Furthermore, majority of the respondents, 68.2 % (36.4% + 31.8%) were aged between 21 and 40 years. The high proportion of the refugee household heads in the age bracket of 41-50 years (21.9%) is indicative of a considerably high life expectancy among refugees in West Nile compared to the host populations check out the life expectancy as released by UBOS in the recent census) and the complicated lifestyle, that the refugees lead in camps. With regard to household size, results in Table 4.2 show that a typical household in a refugee settlement in West Nile has 5 members (59%). The result also shows a high proportion of households (32%) with a very high dependence burden caused by the many members. In such households therefore, the per capita water needs per person is higher which puts the household heads in a complicated situation of rationing the water provisioned by the refugee management agencies and institutions.

4.4 The physicochemical and bacteriological quality of water at source points

Objective 1 assessed the physicochemical and bacteriological quality of water *in situ* at source points in and around the refugee settlements in West Nile. Water for each settlement was drawn from a single point source and therefore, the results in Table 4.3 are based on observations from a single source. At Imvepi 1, the source point is a shallow well in the vicinity of the refugee settlement. At both Pagirinya and Omugo, the water is drawn from borehole systems located 6 and 9 kilometres away from the settlements respectively. The aim of this assessment was to determine the suitability of water at source points in order to establish whether it was fit for human consumption. Four internationally recognized permissible values for the drinking water were used. These were: Indian Council of Medical Research (ICMR), United States Public Health Services (USPHS), World Health Organization (WHO), and European Economic Community (EEC) now, European Union (EU). Permissible ranges were computed from the various standards. The results obtained from assessing the physicochemical and bacteriological quality of the source points were compared with the international and local permissible ranges. The local permissible ranges are specified by Uganda National Bureau of Standards (UNBS) and National Water and Sewerage Corporation (NW&SC). The results are shown in Table 4.3 below;

Table 4.3: International and local permissible values for assessing quality of drinking water

Parameter	Refugee Settlement			International average permissible range	UNBS/NW&SC	Comment
	Pagirinya	Omugo	Imvepi 1			
pH	6.3	6.8	7.7	6.0-9.2	5.5-8.5	Permissible
Turbidity	8.3	8.2	8.9	5-10	5.0	Permissible
TDS	333	451	309	500	700	Permissible
TSS	4.5	4.9	4.1	5.0	0.0	Permissible
Hardness	123	167	144	200-300	500	Permissible
Calcium	43	45	56	75-100	75	Permissible
Magnesium	34	35	40	30-50	50	Permissible
BOD	4.0	4.3	3.1	5.0	5.0	Permissible
EC	362	354	327	300 µmho/cm	300 µmho/cm	Outlier
Chloride	261	293	309	200-250	250	Outlier
Sulphate	60	55	80	150-250	200	Permissible
Total Alkalinity	143	154	161	120 mg/l	120 mg/l	Outlier
Fluoride	<0.1	<0.1	<0.1	0.6-1.5		Permissible
Iron	1.1	1.09	1.7	0.1-0.3	<0.3	Permissible
Lead	ND	ND	ND	0.05-0.10	0.05	No comment

Parameter	Refugee Settlement			International average permissible range	UNBS/NW&SC	Comment
	Pagirinya	Omugo	Imvepi 1			
NO_3-N	13.0	11.0	19.0	10-45	5.0	Permissible
Zinc	0.06	0.04	0.07	5.0-5.5	5.0	Permissible
E. coli (CFU/100 ml)	123	134	109	100ml	0.0	Outlier

Key: pH=Potential hydrogen; TDS= Total Dissolved Solids, TSS=Total Suspended Solids, BOD=Biochemical Oxygen Demand, EC=Electric Conductivity, NO_3-N=Nitrate-Nitrogen, MPN=Most Probable Number, ND=Not Detected;

Source: Laboratory Analysis (April, 2023)

As shown in Table 4.3, the source points of the water pumped to the tanking systems (POD) of the three refugee settlements met the international and national standards of potable water on most of the parameters. It was only *E.coli*, EC, chloride concentration and total alkalinity whose results exceeded the permissible ranges.

The variance in the Electrical Conductivity values surpassing the permissible ranges implied that the water drawn at point sources was not fit for human consumption. Therefore, the water sources were somewhat polluted with chemical compounds, and these might have originated from agricultural runoff since farmers in the areas surrounding the point water sources engage in intensive farming. Intensive farmers use inorganic chemicals such as fertilizers, herbicides, acaricides and pesticides. In regard to chloride concentration, it is important to note that by and large, much as every water must contain chloride ions, these should exist in low concentration and therefore, any deviations from the permissible ranges implies that the source point is susceptible to be polluted by wastewater (Deivayanai et al., 2023; Radjenovic et al 2015; Suthar et al., 2010). The laboratory results show that the observed values were higher than the permissible ranges at both international and local standards. For instance, the UNBS set the concentration of chloride ions in water especially for untreated potable water at 250mg/l. As can be observed from Table 4.3, the values at sources in both refugee settlements exceeded the permissible ranges by 23mg/l, 34mg/l and 41mg/l respectively.

Alkaline water is capable of neutralizing acids. The alkalinity values provide guidance when applying appropriate doses of water treatment chemicals in water and in wastewater treatment processes particularly in coagulation, softening and operational control of anaerobic digestion. In all the samples, alkalinity ranged between 144mg/l to 162 mg/l and yet the permissible threshold is 120mg/l. By implication therefore, the higher values beyond permissible ranges were indicative of contamination. Dwivedi et al. (2023) noted that high levels of alkalinity are indicative of bases in the water. Nsabimana *et al*. (2023) also established that such variations are indicative of groundwater pollution. Therefore, such water ought to be treated before human consumption.

The presence of fecal bacteria (*Escherichia coli*) at the point sources was detected at the three sites, their presence could be because of nearby latrines or a possible human error during sampling collection. The high mean values obtained (123 MPN/ml for Pagirinya, 134 MPN/ml for Omugo and 109 MPN/ml for Imvepi 1) therefore revealed that the contamination exceeded the permissible range and therefore, chlorination of the water before distribution to the refugees was quite important. Further evidence was obtained from the Annual Welfare Reports of Omugo and Pagirinya (2021 and 2022).

Reported cases of waterborne disease outbreaks were cited in the two reports as part of the key health challenges that affected the refugees in the two camps and these were attributed to the declining levels of water quality. Further evidence of contamination of the water by *E. coli* was also cited by one of the WASH officers who revealed that in their settlement, some refugees were not observing the best practices for storing chlorinated water. One of the case examples given was the tendency of some households to using big saucepans and bigger basins for storing water. In the same households, the main method used in drawing water from the storage container was dipping using a cup. In such a situation, therefore, the stakes are high that the water will easily be contaminated. In relation, another WASH Officer noted that in households with young children, there was a big chance that they will always play with the water including dumping foreign materials such as soil and other objects in it. In such a situation, the water ends up becoming contaminated.

In conclusion, the above findings showed that most physicochemical parameters of water used in refugee settlements were within the permissible ranges fixed by authorities at both local and international levels. Although the water met the standards to some extent, the study established that the water had a high chloride content, EC, total alkalinity while it was also biologically unfit for human consumption because of the concentration of *E. coli* that surpassed the permissible ranges at both local and international levels. Therefore, disinfection of the water with chlorine was important before the actual use of the water by the refugees. The importance of disinfecting water with Chlorine is stressed by Costa *et al.* (2021) and Maqbool et al. (2021) who highlighted that chlorination has the advantage of providing a persistent residual in water which keeps its safe from pathogens for 24 hours

4.5 Efficacy of chlorine disinfection programs in refugee settlements in West Nile

Objective two (2) sought to examine the efficacy of the chlorine disinfection programmes in the selected settlements. The chlorination programmes used in the selected refugee settlements are centralized as discussed below.

4.5.1 Chlorination Programme in Imvepi 1

In this refugee settlement, the water is pumped from the source point using motorized boreholes. The pumped water goes through a system in a water house (see Plate 4.1) after which it is stored in large reservoir tank. The water flows through a piped network to different points of distribution. The refugee households access the water at stand pipes. The chlorination is done at the distribution tanks before any water is drawn from the points of distribution by the households. The average free residual chlorine at this site was 1.2 mg/L (Table 4.4).

Plate 4. 1: Chlorination System at Imvepi 1

4.5.2 Chlorination Programme in Pagirinya Settlement

At Pagirinya Settlement, water is drawn by the households from designated tap stands. The tap stands have running water which is distributed by the tank systems (Figure 5.4). The water at the points of distribution is treated with chlorine before any household can be allowed to draw water. This system is equally rated by this study as effective because the harmful bacteria, viruses, and other microorganisms that can cause waterborne diseases are all killed at this point of distribution. However, in 103 households where water was stored for more than recommended 24 hours after collection from the point of distribution, the average free residual chlorine was 1.3 mg/L and less (Table 4.4).

Plate 4. 2: Chlorination System at Pagirinya

4.5.3 Chlorination Programme in Omugo Settlement

At Omugo Settlement, water is accessed from the stand pipes by the refugees. These have chlorinated running water. Thus, as is the case with Imvepi 1 and Pagirinya, the refugees in Omugo equally access treated water for home use. This system is also rated as ideal and therefore, the water drawn from this source is fit for human consumption. The average FRC in the water samples collected from these households was 1.2 mg/L (Table 4.4). No sign of decline in quality of water was detected at the taps at the POD through the swab test, implying that any observed recontamination of water occurred at the point of use. This assumption was drawn basing on the fact that every observed person who fetched water from POD in either settlement used a jerrycan to ferry water to their respective housing units that were located averagely, 300 meters away from the POD.

Table 4.4: Mean Free-residual chlorine at points of distribution

Refugee Settlement	**Free residual chlorine (mg/L)**
Imvepi 1	1.2± 0.112
Pagirinya	1.3± 0.161
Omugo	1.2± 0.142

Source: Field data

This finding implies that the chlorination programmes in the three refugee settlements were satisfactory and capable of limiting the spread of waterborne diseases that had been reported by Dutta (2023) which was about 3 to 6 months before this study. The FRC at all the POD was 0.5 mg/L implying that the chlorination programmes were efficacious. This inference agrees with the observations of Aliet *et al.* (2021) that in humanitarian settings, free residual chlorine (FRC) levels in chlorinated water supplies should be between 0.2–0.5 mg/L at the point of distribution. This observation clearly testifies that the WASH programmes in the sampled refugee settlements were following the current SPHERE guideline for water chlorination in humanitarian emergencies. The utilization of a central chlorination system established by this study is applauded by Wu *et al* (2021) who noted that in humanitarian settings, there is lack of skilled personnel and appropriate technological gear in an individual household to apply chlorine on their own and therefore, to increase efficacy and efficiency of application, a centralized system at the POD is better. Together with the negative swab test results at the tap of either POD, it is eminent that possible recontamination of water was induced by the nature of the storage conditions at the household level (point of use), since every household drew water using a jerrycan. The likely contamination on transit from POD to POU was considered insignificant, since the refugees ferried water in jerrycans with lids.

4.6 Relationship between storage conditions at the point of use, free residual chlorine decay and bacteriological load of water

Objective three (3) assessed the relationship between storage conditions at point of use, free chlorine decay and bacteriological load of water. Partial correlation analysis was performed on data from Pagirinya, Imvepi 1 and Omugo settlements in West Nile. The partial correlation was computed between 6 input variables and FRC data. Results in Table 4.3 show that the established free residual chlorine at the point of distribution has a significant positive relationship with the free residual chlorine at the households. The negative coefficients in Table 4.5 therefore imply that free residual chlorine decreased at point of use whenever there was an increase in the magnitude of the five input factors, namely elapsed time, electrical conductivity, water temperature, pH and turbidity. While negative correlations existed between free residual chlorine; EC, water temperature and turbidity throughout, two refugee settlements (Pagirinya and Omugo) had positive correlations between free residual chlorine and elapsed time.

Table 4.5: Relationship between water quality variables and free residual chlorine at point of use

Water quality variables	Imvepi 1	Pagirinya	Omugo
FRC	0.14	0.19	0.12
Elapsed time	-0.10	0.02	0.06
EC	-0.01	-0.03	-0.02
Water temperature	-0.10	-0.10	-0.09
pH	-0.02	-0.01	-0.04
Turbidity	-0.01	-0.03	-0.04

FRC=Free residual chlorine; EC=Electrical conductivity; p=0.01

Findings revealed that refugees stored the chlorinated water beyond the recommended storage. Wu and Dorea (2021) reported that FCR decay was affected by water storage conditions. This practice deviated from the standard procedures reported by Wu and Dorea (2021) and Ali *et al*. (2021) that the recommended storage period for chlorinated water is 24 hours. Beyond that time, the free residual chlorine has completely decayed and therefore any intruder pathogens can be catastrophic. Longer storage hours especially at night predicted a low rate of the decay of FRC compared to day time. The negative coefficients for water temperature in Table 4.5 above are explained by the time period of collecting the water samples from the households. All the samples were collected during day time. The reasons explaining this scenario is two-fold. Firstly, during night time, the temperatures are low. Much as this study never delved into measuring day and night temperatures at the study sites, studies (such as Nimusiima et al., 2013) have shown that West Nile usually has blue skies mostly during the dry seasons and cold nights because of absence of notable or visible cloud cover. Secondly, at night, there is limited or no contact between the users and the water. In comparison, shorter storage durations during day time were associated with a high rate of decay of free residual chlorine. Studies (such as Kansiime *et al*., 2016; Nimusiima *et al*., 2013) have shown that West Nile region experiences high day temperatures especially during the dry seasons (December to March and June to August). Therefore, this could have also caused the rapid dissociation of free residual chlorine from the water storage devices. Coupled with more frequent use of the water, the rates of decomposition of the free residual chlorine were high. However, this observation was common with new arrivals that stayed in tented structures which trapped heat during the daytime leading to humid interior conditions. It was less common with households that stayed in constructed structures.

An inverse significant relationship ($p<0.01$) was established between EC and free residual chlorine decay. This result is explained by the fact that EC may manifest in a water sample because of salts, metals, and dissolved organics, among others, implies that these compounds are likely to confound the likely relationship between EC and free residual chlorine decay. This finding supports the observation of Leziart *et al*. (2019) that the extraneous influence of compounds such as salts, metals and dissolved organics exerts a high chlorine demand. As a result, the rate at which free residual chlorine dissociates is high. A similar inverse significant relationship ($p<0.01$) was established between turbidity and free residual chlorine decay. The relationship between turbidity and free residual chlorine decay is confounded by turbidity-causing compounds including the presence of oxidizable organic material such as lipids or suspended materials such as silt, sand, soil, plankton and debris. These have the potential of exerting a large chlorine demand. This accounts for why this study endeavoured to establish what the predictors of the recontamination of the water were in a typical household in a refugee settlement in West Nile by specifically assessing how the quality of the water changed between the points of distribution (POD) and points of use (POU). Indeed, of all the water samples collected from 46 POD and 324 POU (households) had varied results regarding FRC and Fecal coliforms (Table 4.6).

Table 4.6: Results of Mann-Whitney U test for comparisons between water quality at POD and PoU in refugee settlements in West Nile.

Statistical Parameter	PoD (n=12)	PoU (n=324)	p-value
Free residual chlorine (mg/L)			
Mean	0.42	0.16	0.031*
Median	0.2	0.1	
Range	0-1	0-1	
Fecal coliform (CFU /100 mL)			
Mean	0.2	39	0.016*
Median	0	0	
Range	0-100	0-1,321	

*Significant at 0.05

As shown in Table 4.6, free residual chlorine at points of distribution (0.42 mg/L) was close to SPHERE threshold (0.5 mg/L), the concentration declined greatly at the points of use with the average concentration being 0.16 mg/L. Therefore, there was a significant difference (p=0.031<0.05) implying that that FRC decomposition largely occurred due to the storage and use conditions at POU.

With regard to faecal coliform counts, Table 4.6 shows that a high proportion of the water collected from POU were contaminated and unfit for human consumption (Range =0-1,321> 0-100). There was a significant difference between the CFU mg/L in the water samples at Point of distribution and point of use (p=0.016<0.05). This finding implies that the possibility of water recontamination was high and therefore, the households were vulnerable to outbreaks of diarrheal diseases. This finding is supported by Yates *et al*. (2017) and Bautista-de Los Santos *et al*. (2019) that low free chlorine concentrations encourage the recontamination of water thereby predicting a possibility of waterborne disease outbreaks.

The result in Table 4.6 have shown that in the selected refugee settlements, the quality of water deteriorated at point of use. Results from multivariate logistic regression analysis (Table 4.7) have shown that that households with a head without formal education were significantly more associated with fecal coliform contamination of water than one who had completed secondary education (AOR: 2.41, 95% CI (1.14 3.99)), this is anticipated to limited access to information and knowledge of safe water handling and storage. The study findings further showed that households with wide-mouthed water storage devices were significantly more susceptible to fecal coliform contamination of water compared to their counterparts who used narrow mouthed containers (AOR: 3.34, 95% CI (1.58 1.86)). This finding resonates with earlier observations by Akhter *et al*. (2020) and Packiyam *et al*. (2016) that wide-necked containers are known for exposing stored water to contaminants while Pickering et al.

(2010) also highlighted that when water is kept in wide-necked containers, the frequency with which it comes in contact with the hands is higher. This is even worse when the dipping devices are not well maintained and therefore, they become a pathway through which the contaminants re-enter the chlorinated water in the households. This finding is a clear testimony of the findings of Mugumya et al. (2020) that pouring water, especially by tilting the storage device or container is the safest way of drawing water compared to dipping.

The study equally determined whether there was any variation between the FRC decay and therefore, recontamination of water across the three sampled sites, ANOVA (Analysis of Variance) was used (Table 4.7). Results showed that the microbial quality of water never varied between POU ($p=0.128>0.05$). The water samples drawn from the households had high concentrations of E coli and Total coliform which provides a further proof of the results reported earlier in Table 4.6. This, therefore, indicates that drinking water used in these households was not suitable for human consumption and thus higher chances of contraction of water-related diseases.

Table 4. 7 : Summary of 1-way ANOVA for microbial quality of drinking water at POU

Model		Sum of Squares	df	F	Sig.
	Between groups	21.626	2	4.229	.128
	Within groups	16.318	323		
	Total	37.944	325		

ANOVA=Analysis of Variance; DF=Degrees of Freedom

The recontamination of chlorinated water likely to have been influenced by water handling and hygiene practices as well as the storage conditions. To determine the impact of these factors, multiple logistic regression was computed to isolate the factors causing variation in the quality of water at POU. In regard to care for the water stored in the house, this study showed that households which stored their collected water anywhere were significantly more vulnerable to fecal coliform contamination compared to those that had a designated elevated place for storage (AOR: 3.11, 95% CI (0.65 8.99)). More evidence of the cause of fecal coliform contamination of the water was associated with the hygiene status of the household and more so the cleanliness of the water storage devices and the hygienic conditions of the person drawing water in regard to the cleanliness of their fingers. As shown in Table 4.8, storage and drawing devices were significantly more prone to fecal coliform contamination compared to those who kept these devices clean (AOR: 2.91, 95% CI (0.75 2.12)). This finding testifies earlier studies by Rufener *et al*. (2010) and Mattioli *et al*. (2013) that dirty hands could contaminate water not only through handling during collection and transportation as evidence from Tanzania showed that diarrheal-causing viruses and *E. coli* were detected on the hands of water handlers suggesting that the hands were important carriers for diarrheal illnesses among the communities using chlorinated water.

Another key finding of the study was refugee households suffered from frequent water shortages and therefore, in the previous month, households which suffered from drinking water shortage had significantly higher fecal contamination than their counterparts (AOR: 3.82, 95% CI(1.1 3.39)).Table 4.8 further shows that household drinking water lacking free residual chlorine was significantly more contaminated with fecal coliforms than drinking water which had free residual chlorine (AOR: 6.35, 95% CI (4.66 12.99)). Dipping and storage of water in a separate container never had a significant impact on fecal coliform contamination of the stored water.

Table 4. 8: Determinants of stored drinking water fecal contamination in refugee communities in West Nile.

Variable	Unadjusted ORs (95% CI)	Adjusted ORs (95% CI)	p-values	Reference factor
Household head with formal education	1.89(1.11-3.78)	2.41 (1.14-3.99)	0.013*	HH completed secondary education and above
Household head completed primary education	1.13(0.63-2.21)	1.21 (0.6-2.66)	0.54	
Wide-mouthed water container	2.8(1.41-1.56)	3.34(1.58-1.86)	0.018*	Narrow-mouthed water container (≤ 3cm diameter)
Both types water container	0.65 (0.33-1.76)	0.89(0.6-.84)	0.82	
Water not stored in a separate container	1.33(0.76-2.11)	1.53(0.67-2.34)	0.19	Drinking water kept in a separate container
Container kept on the floor inside the house	2.33(0.53-7.27)	3.11(0.65-8.99)	0.002*	Drinking water container kept in an elevated place
Container kept anywhere outside the house	1.48(0.41-6.01)	0.97(0.21-4.4)	0.86	
Dipping	1.12 (0.59-1.77)	0.88(0.31-2.86)	0.79	Pouring to take out water
Both dipping and pouring	0.87(0.54-1.99)	1.11(0.49-2.16)	0.81	
Water container never appeared clean	1.52(0.79-2.65)	2.91(0.75-2.12)	0.007*	Water container appeared clean
Water shortage within the last one week	2.56(0.58-2.93)	3.82(1.1-3.39)	0.019*	No water shortage within the last one week
Zero FRC concentration	7.11(5.3-13.44)	6.35(4.66-12.99)	0.001*	≥0.2 mg/l FRC concentration
>0, <0.2mg/l FRC concentration	2.22(1.16-4.22)	1.97(0.73-3.10)	0.17	

At the time of collecting water samples from the households as well as on the days when the survey questionnaires were administered the, observation made indicated that most of the refugees were not observing standard personal hygiene practices. For example: adults had long dirty finger nails, absence hand washing points; where they existed, no soap was provided. The same persons draw water from plastic drums and bigger saucepans. This increases chances of water contamination, and spread of water borne diseases. In some situations, especially for the new arrivals that were housed in tarpaulin structures that tend to have high humid conditions which affect the stability of FRC in the water containers.

4.7 Strategies for better management of chlorinated water at point of consumption in refugee settlements

Objective four (4) examined the strategies for the better management of chlorinated water at the points of consumption in the selected refugee settlements. The following results were obtained;

Table 4. 9: Strategies for better management of chlorinated water by households in the refugee settlements.

Statement	D	N	A	Mean	St. Dev
1. Sensitizing the households on safe water storage and handling at point of use is important	104 32.1%	2 0.6%	218 67.3%	3.81	0.705
2. WASH clubs in the refugee settlements are capable of improving water and sanitation management at household level	51 15.8%	6 1.9%	267 82.5%	4.12	0.755
3. Establishing a WASH committee comprising all agency staff would improve water quality management in my household	63 19.5%	28 8.6%	233 71.9%	3.92	0.901
4. Supporting us with water collection and storage devices would equally improve the levels of water quality in my household	10 3.1%	68 21.0%	237 75.9%	4.00	0.935

Statement	D	N	A	Mean	St. Dev
5. Increasing the numbers of taps nearby would also reduce on numbers of days or weeks for storing reserve water	84 25.9%	0 0.0%	240 74.1%	4.01	0.651

D=Disagreed, N=Neutral, A= Agree
Mean: 1.00-2.45=Disagreed; 2.5-3.45=Undecided; 3.5-5.00=Agreed
Source: Field Data (March, 2023)

Results in Table 4.8 indicate that majority of the respondents 67.3% (n=213) and agreed that sensitizing the households on safe water storage and handling at point of use is important. The finding further indicates a mean value of 3.81±0.705 (on a 5-point Likert scale). This therefore implies most respondents were optimistic that sensitization of the households on safe water storage and handling practices was an important strategy that would reduce on the recontamination of the chlorinated drawn from the various points of distribution in the refugee settlements. Through observation on the days of collecting water samples from each household, it was observed that majority of the households were not observing the requirements for the safe storage and management of the treated water stored in their units. This strategy is accredited by Sikder et al. (2020) who noted that continuous monitoring with emphasis on awareness creation among the users engenders complete behaviour change.

Table 4.9 further still shows that regarding the ability of forming WASH clubs in the refugee settlements and their likelihood of improving water and sanitation management at the household level, most of the respondents agreed 267(72.5%). The findings further indicate a mean value of 4.12± 0.755 (on a 5-point Likert scale) which is confirmatory evidence that the majority of the respondent household heads were optimistic that if the supporting institutions could help the refugees to form WASH clubs, the storage and hygiene conditions for the stored water would improve greatly. The assertion comports with the views of Alam et al. (2020) who revealed that refugees in their study sites were open to using other methods of water treatment than chlorine. These treatment methods were perceived to be easy to use and were considered more beneficial than chlorine. To this effect, Alam and colleagues recommended the need for involving community and religious leaders in formulating and delivering messages that addressed water taste and smell of the treated water so that any mistrust and allayed fears are identified and addressed to maximize the willingness of the refugees to adopt safe water management practices post-treatment.

Table 4.9 further shows that regarding whether establishing a WASH committee comprising all agency staff would improve water quality management in refugee households, the majority of the respondents 233 (71.9%) agreed. The finding further indicates a mean value of 3.92 ± 0.901 (on a 5-point Likert scale) which implies that most of the respondents were convinced that a WASH team that comprised the staff from the various agencies and institutions that are supporting the refugees in West Nile would also bring about an improvement in the management of the quality of water stored in refugee households. This inference rhymes the views of Faruque *et al*. (2022) who suggested that in any humanitarian situation, humanitarian agencies should actively engage and involve the refugees in the regular monitoring of drinking water sources and more so in the monitoring of free residual chlorine levels of water points.

Table 4.9 equally indicates that in regard to whether supporting refugees with water collection and storage devices would likely improve the levels of water quality, majority 246 (75.9%) agreed. The finding further indicates a mean value of 4.00± 0.935 (on a 5-point Likert scale) which confirms that the refugee households were in dire need of devices to use for collecting and storing water. The majority of the respondents were using water collection devices that were either donated by host community members as well as those that were collected and sold to them at a cheaper rate by garbage collecting teams in the neighbouring towns. Therefore, providing the households with collection and storage containers would improve in the cleanliness and hygiene conditions in which the water was stored and therefore, this would minimize the magnitude of water recontamination.

The study findings in Table 4.9 above indicate that in relation to whether increasing the number of points of distribution would also reduce on numbers of days or weeks for storing reserve water, the majority of the respondents, 240(74.1%) were in agreement with the suggestion. The finding additionally indicates a mean value of 4.01± which confirmed that the distance between the housing units and points of distribution contributed a lot to the storage of water for long periods leading to the fast dissociation of free residual chlorine. Therefore, to abate the rate of water recontamination, the respondents were optimistic that if the leadership of their refugee settlement could increase on the current number of points of distribution, the existing gaps caused by long distances to access water at the points of distribution would reduce significantly and therefore, the storage period would equally reduce considerably.

4.8 Conclusion

Study results have shown that much as chlorination programmes in refugee settlements in West Nile have guaranteed that households access quality water for use, the storage conditions at household level bring about a downgrade of the quality of the water and exposes it to recontamination. The rapid decay of free residual chlorine was associated with the shelter temperatures, poor hygiene, long storage periods, poor storage conditions and lack of adequate water storage vessels. In the next chapter, conclusion is drawn and key recommendations are made.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The study results have shown that refugee households are vulnerable to outbreaks of waterborne diseases, despite the fact that they draw chlorinated water from points of distribution that are spread across the refugee settlements. The high incidence of recontamination of the water was reported by this study. In this chapter, a conclusion is drawn while practical recommendations for addressing the reported water storage challenges are also provided.

5.2 Conclusion

Chlorinating water at POD is not an end in itself. It is rather a means by which the quality of water is improved before it is used at POU. At POU, water recontamination is possible when the water is not well stored. Thus, the outbreak of waterborne diseases will continue to be a major problem in the refugee settlements of Uganda unless efforts are made to correct the current outstanding problem of chlorinated water recontamination at the POU. Its concluded that as long as this matter of recontamination of treated water is not duly addressed, the efficacy of chlorinating the water at POD will be lost since the findings from the water samples collected at POU showed a drastic reduction in the FRC sometimes even below the threshold (0.2 mg/L).In absolute and relative terms, this study established that most of the predisposing factors leading to the loss of FRC are preventable since they are water-user-related.

5.3 Implications of the study

For quite a long time, waterborne disease outbreaks have been reported in refugee settlements in Uganda. Yet, in many institutional and ministerial budgets, they vouch that chlorination is among the budget lines allocated considerable sums of money. This study has therefore brought to the fore that the chlorination programmes operating in refugee settlements in Uganda are efficacious and therefore, the waterborne diseases are attributed to the recontamination of the water at the point of use. This study therefore has implications to the planners and policy makers on refugee welfare in Uganda, given our prime importance on refugee issues both at continental and global level. It is a wake-up call that the existing policies on water treatment be twinned with awareness creation so that the overall goal of supplying portable water to the refugees is realized. To the practitioners of refugees' livelihoods, this study also provides insights into the need for devising the most plausible solutions to the recontamination of water at the point of use. This will attract grand strategies that will shift the focus from managing the points of distribution and points of use. To theory, the findings add to the knowledge base about the SPHERE Guidelines for water quality in emergency and humanitarian settings and call for a need to devise additional guidelines for water at point of use especially that which is kept for long hours.

5.4 Recommendations

The study makes the following recommendations

1. There is need for the management refugees' affairs in Uganda to prioritize WASH campaigns throughout the settlements. For effectiveness, these should be

localized such that the refugee households are incorporated as members of the committees.

2. There is a need for distributing about 5 water collection devices to each refugee household to enable them to fetch water from the POD with ease and with less intention to store it for long.
3. Deficiencies in the entire WASH conditions of the refugee households especially hand washing with soap and water after using the toilets by providing tippy tap for refugee households household.
4. There is need to establish about 100 POD per settlement compared to the current 46 for all the three settlements. This strategy will limit the water storage hours.

5.5 Areas for further research

The study has confirmed that recontamination of water occurs at the household level in refugee settlements in Uganda despite the efficacy of the established chlorination programmes. Nonetheless, plausible conclusions that are generalizable can barely be drawn since only three refugee settlements out of a dozen or more settlements in Uganda were selected in this study. Future studies should consider extending this scope of research to cover at least 80% of the refugee settlements in Uganda.

References

Akhter, M., Uddin, S.M.N., Rafa, N., Hridi, S.M., Staddon, C. and Powell, W., 2020. Drinking water security challenges in Rohingya refugee camps of cox's bazar, Bangladesh. *Sustainability*, *12*(18), p.7325.

Alam, M.U., Unicomb, L., Ahasan, S.M., Amin, N., Biswas, D., Ferdous, S., Afrin, A., Sarker, S. and Rahman, M., 2020. Barriers and Enabling Factors for Central and Household Level Water Treatment in a Refugee Setting: A Mixed-Method Study among Rohingyas in Cox's Bazar, Bangladesh. *Water*, *12*(11), p.3149.

Alexandratos, S.D., Barak, N., Bauer, D., Davidson, F.T., Gibney, B.R., Hubbard, S.S., Taft, H.L. and Westerhof, P., 2019. Sustaining water resources: Environmental and economic impact. *ACS Sustainable Chemistry & Engineering*, *7*(3), pp.2879-2888.

Ali, S. I., Ali, S. S. and Fesselet, J. F. 2021. Evidence-based chlorination targets for household water safety in humanitarian settings: recommendations from a multi-site study in refugee camps in South Sudan, Jordan, and Rwanda. *Water Research*, *189*, p.116642.

Ali, S.I., Ali, S.S. and Fesselet, J.F., 2015. Effectiveness of emergency water treatment practices in refugee camps in South Sudan. *Bulletin of the World Health Organization*, *93*, pp.550-558.

Alim, M. A., Rahman, A., Tao, Z., Samali, B., Khan, M. M. and Shirin, S. 2020. Suitability of roof harvested rainwater for potential potable water production: A scoping review. *Journal of cleaner production*, *248*, 119226.

Alshenqeeti, H., 2014. Interviewing as a data collection method: A critical review. *English linguistics research*, *3*(1), pp. 39-45.

Amaga, A.L. 2018. Refugees are Unfortunate Human Beings. London: HBJ

Anthonj, C., Fleming, L., Cronk, R., Godfrey, S., Ambelu, A., Bevan, J., Sozzi, E. and Bartram, J., 2018. Improving monitoring and water point functionality in rural Ethiopia. *Water*, *10*(11), p.1591.

Anwar, S.N.B.M., Alvarado, V. and Hsu, S.C., 2021. A socio-eco-efficiency analysis of water and wastewater treatment processes for refugee communities in Jordan. *Resources, Conservation and Recycling*, *164*, p.105196.

Appiah-Brempong, E., Harris, M.J., Newton, S. and Gulis, G., 2018. A framework for designing hand hygiene educational interventions in schools. *International Journal of Public Health*, *63*(2), pp.251-259.

Banning, E. B., 2021. Sampled to Death? The Rise and Fall of Probability Sampling in Archaeology. *American Antiquity*, *86*(1), pp. 43-60.

Bautista-de Los Santos, Q.M., Chavarria, K.A. and Nelson, K.L., 2019. Understanding the impacts of intermittent supply on the drinking water microbiome. *Current opinion in biotechnology*, *57*, pp.167-174.

Belmino da Silva, G. A., dos Santos, W. B., de Almeida Lopes, T. S., Ferreira, W. B., & Lima

Besic, A., Obradovic, Z., Dautbegovic, A. and Obradovic, A., 2017. The effect of temperature and chlorine residual on the presence of Legionella spp. in water systems of public and tourist facilities. *Journal of Health Sciences*, *7*(1), pp.50-58.

Binti, D.R.,2021. Face and content validity for the special education leadership (integration) questionnaire in Malaysia. *Turkish Journal of Computer and Mathematics Education, 12*(11), pp.5172-5178.

Branz, A., Levine, M., Lehmann, L., Bastable, A., Ali, S.I., Kadir, K., Yates, T., Bloom, D. and Lantagne, D., 2017. Chlorination of drinking water in emergencies: a review of knowledge to develop recommendations for implementation and research needed. *Waterlines*, pp.4-39.

Bwire, G., Orach, C.G., Aceng, F.L., Arianitwe, S.E., Matseketse, D., Tumusherure, E., Makumbi, I., Muruta, A., Merrill, R.D., Debes, A. and Ali, M., 2021. Refugee settlements and cholera risks in Uganda, 2016–2019. *The American Journal of Tropical Medicine and Hygiene*, *104*(4), p.1225.

Carter, R.C., 2021. Rural Community Water Supply: Sustainable services for all.

Cassivi, A., Tilley, E., Waygood, E.O.D. and Dorea, C., 2021. Household practices in accessing drinking water and post collection contamination: a seasonal cohort study in Malawi. *Water research*, *189*, p.116607.

CDC. 2022 October 20. Household Water Treatment. https://www.cdc.gov/healthywater/global/household-water-treatment.html

Chaukura, N., Marais, S. S., Moyo, W., Mbali, N., Thakalekoala, L. C., Ingwani, T., ... and Nkambule, T. T. 2020. Contemporary issues on the occurrence and removal of disinfection byproducts in drinking water:A review. *Journal of Environmental Chemical Engineering*, *8*(2), p.103659.

Cipolletta, G., Ozbayram, E.G., Eusebi, A.L., Akyol, Ç., Malamis, S., Mino, E. and Fatone, F., 2021. Policy and legislative barriers to close water-related loops in innovative small water and wastewater systems in Europe: A critical analysis. *Journal of Cleaner Production*, *288*, p.125604

Costa, J., Mesquita, E., Ferreira, F., Rosa, M. J. and Viegas, R. M. 2021. Identification and modelling of chlorine decay mechanisms in reclaimed water containing ammonia. *Sustainability*, *13*(24), p.13548.

De Santi, M., Ali, S.I., Arnold, M., Fesselet, J.F., Hyvärinen, A.M., Taylor, D. and Khan, U.T., 2022. Modelling point-of-consumption residual chlorine in humanitarian response: Can cost-sensitive learning improve probabilistic forecasts?. *PLoS Water*, *1*(9), p.e0000040.

De Santi, M., Khan, U.T., Arnold, M., Fesselet, J.F. and Ali, S.I., 2021. Forecasting point-of-consumption chlorine residual in refugee settlements using ensembles of artificial neural networks. *npj Clean Water*, *4*(1), p.35.

Deivayanai, V.C., Karishma, S., Thamarai, P., Yaashikaa, P.R. and Saravanan, A., 2023. A comprehensive review on electrodeionization techniques for removal of toxic chloride from wastewater: Recent advances and challenges. *Desalination*, p.117098.

Devi, P. and Dalai, A. K. 2021. Implications of breakpoint chlorination on chloramines decay and disinfection by-products formation in brine solution. *Desalination*, *504*, p.114961.

Duran-Encalada, J. A., Paucar-Caceres, A., Bandala, E. R. and Wright, G. H. 2017. The impact of global climate change on water quantity and quality: A system dynamics approach to the US–Mexican transborder region. *European Journal of Operational Research*, *256*(2), 567-581.

Dutta, H., 2023. Insights into different facets of the refugee crises–environment nexus. *Journal of Social and Economic Development*, pp.1-24.

Dwivedi, Y.D., Kumar, P.M., Gupta, A., Ahalya, N., Rana, D., Sharma, M. and Surakasi, R., 2023. Experimental study on the treatment of urban garment industry wastewater to mitigate groundwater contamination using a solar evaporative still. *Urban Climate*, *49*, p.101435.

Faruque, A.S.G., Alam, B., Nahar, B., Parvin, I., Barman, A.K., Khan, S.H., Hossain, M.N., Widiati, Y., Hasan, A.M., Kim, M. and Worth, M., 2022. Water, Sanitation, and Hygiene (WASH) Practices and Outreach Services in Settlements for Rohingya Population in Cox's Bazar, Bangladesh, 2018–2021. *International Journal of Environmental Research and Public Health*, *19*(15), p.9635.

Fischer, A., Hope, R., Manandhar, A., Hoque, S., Foster, T., Hakim, A., Islam, M.S. and Bradley, D., 2020. Risky responsibilities for rural drinking water institutions: The case of unregulated self-supply in Bangladesh. *Global Environmental Change*, *65*, p.102152.

Fisher, I., Kastl, G.andSathasivan, A. 2019. Cost-effective chlorination strategies for drinking water. *Water e-Journal*, *4*(1), pp.1-13.

García-Ávila, F., Sánchez-Alvarracín, C., Cadme-Galabay, M., Conchado-Martínez, J., García-Mera, G. and Zhindón-Arévalo, C., 2020. Relationship between chlorine decay and temperature in the drinking water. *MethodsX*, *7*, p.101002.

Gazzeh, K. and Abubakar, I.R., 2018. Regional disparity in access to basic public services in Saudi Arabia: A sustainability challenge. *Utilities Policy*, *52*, pp.70-80.

Ghernaout, D. and Elboughdiri, N. 2020. Disinfection by-products: Presence and elimination in drinking water. *Open Access Library Journal*, *7*(2), pp.1-27.

Government of Western Australia (2015). Standard drinking water sampling procedure– microbiological. Department of Health. https://www.health.wa.gov.au/~/media/Files/Corporate/general-documents/water/Drinking-water/Standard_drinking_water_sampling_technique_-microbiological.pdf

Günther, I. and Schipper, Y., 2013. Pumps, germs and storage: the impact of improved water containers on water quality and health. *Health Economics*, *22*(7), pp.757-774.

Hassan Omer N (2020) Water Quality Parameters. Water Quality - Science, Assessments and Policy. IntechOpen. Available at: http://dx.doi.org/10.5772/intechopen.89657.

Hayder, R., Hafeez, M., Ahmad, P., Memon, N., Khandaker, M.U., Elqahtani, Z.M., Al-Buriahi, M.S., Mahmoud, Z.M. and Ahmed, M.N., 2022. Heavy metal estimation and quality assurance parameters for water resources in the northern region of Pakistan. *Water*, *15*(1), p.77.

IFRCRCS, I.2008. Household water treatment and safe storage in emergencies: A field manual for Red Criss/ Red Crescsent Personnel and Volunteers. Geneva: IFRCRCS.

Iliyasu, R. and Etikan, I., 2021. Comparison of quota sampling and stratified random sampling. *Biom. Biostat. Int. J. Rev*, *10*, pp.24-27.

Kalyegira, J., 2022. Basic psychological needs satisfaction and psychological well-being of refugees in Africa. *Discover Psychology*, *2*(1), pp.1-15.

Kansiime, M.K. and Mastenbroek, A., 2016. Enhancing resilience of farmer seed system to climate-induced stresses: Insights from a case study in West Nile region, Uganda. *Journal of rural studies*, *47*, pp.220-230.

Kioko, K.J. and Obiri, J.F., 2012. Household attitudes and knowledge on drinking water enhance water hazards in peri-urban communities in Western Kenya. *Jàmbá: Journal of Disaster Risk Studies*, *4*(1), pp.1-5.

Koonin, M., 2014. Validity and reliability. *Research matters*, pp.252-260.

Kumar, R., 2019. *Research methodology: A step-by-step guide for beginners*. Sage.

Levy, K., Nelson, K.L., Hubbard, A. and Eisenberg, J.N., 2008. Following the water: a controlled study of drinking water storage in northern coastal Ecuador. *Environmental health perspectives*, *116*(11), pp.1533-1540.

Léziart, T., Dutheil de la Rochere, P.M., Cheswick, R., Jarvis, P. and Nocker, A., 2019. Effect of turbidity on water disinfection by chlorination with the emphasis on humic acids and chalk. *Environmental technology*, *40*(13), pp.1734-1743.

Lindmark, M., Cherukumilli, K., Crider, Y. S., Marcenac, P., Lozier, M., Voth-Gaeddert, L., ... and Pickering, A. J. 2022. Passive In-Line Chlorination for Drinking Water Disinfection: A Critical Review. *Environmental science & technology*, *56*(13), pp. 9164-9181.

Lingle, C. K., Schumacher, A. J., Rosauer, M. L., Silbernagel, K. M., & Deterding, A. (2022). 3M™ Petrifilm™ Rapid Aerobic Count (RAC) Plate Method for the Enumeration of Aerobic Bacteria on Selected Surfaces: AOAC Official MethodSM 2015.13. *Journal of AOAC International*, *106*(1), 165–170. https://doi.org/10.1093/jaoacint/qsac122

Mahamud, A.S., Ahmed, J.A., Nyoka, R., Auko, E., Kahi, V., Ndirangu, J., Nguhi, M., Burton, J.W., Muhindo, B.Z., Breiman, R.F. and Eidex, R.B., 2012. Epidemic cholera in Kakuma Refugee Camp, Kenya, 2009: the importance of sanitation and soap. *The Journal of Infection in Developing Countries*, *6*(03), pp.234-241.

Maqbool, T., Zhang, J., Qin, Y., Asif, M. B., Ly, Q. V., and Zhang, Z. 2021. Fluorescence moieties as a surrogate for residual chlorine in three drinking water networks. *Chemical Engineering Journal*, *411*, p.128519.

Mattioli, M.C., Pickering, A.J., Gilsdorf, R.J., Davis, J. and Boehm, A.B., 2013. Hands and water as vectors of diarrheal pathogens in Bagamoyo, Tanzania. *Environmental science & technology*, *47*(1), pp.355-363.

McClain, J. and Paye, P.D., 2017. Household Water Quality and Management Survey: Paynesville City, Greater Monrovia.

Meierhofer, R., Wietlisbach, B. and Matiko, C., 2019. Influence of container cleanliness, container disinfection with chlorine, and container handling on recontamination of water collected from a water kiosk in a Kenyan slum. *Journal of Water and Health*, *17*(2), pp.308-317.

Mugumya, T., Isunju, J.B., Ssekamatte, T., Wafula, S.T. and Mugambe, R.K., 2020. Factors associated with adherence to safe water chain practices among refugees in Pagirinya refugee settlement, Northern Uganda. *Journal of Water and Health*, *18*(3), pp.398-408.

Musz-Pomorska, A. and Widomski, M. K. 2020. Variant analysis of the chlorination efficiency of water in a selected water supply network. *Proceedings of ECOpole*, *14*(1),pp.19-28.

Mwesigwa, A.B. (2019). Uganda's Refugee Policy: A Case of Bidi Bidi Camp. Unpublished Thesis, Master of Public Administration and Management, Makerere University, Kampala-Uganda.

Nakano, D. and Muniz Jr, J., 2018. Writing the literature review for empirical papers. *Production*, *28*.

Ngene, B.U., Nwafor, C.O., Bamigboye, G.O., Ogbiye, A.S., Ogundare, J.O. and Akpan, V.E., 2021. Assessment of water resources development and exploitation in Nigeria: A review of integrated water resources management approach. *Heliyon*, *7*(1), p.e05955.

Nimusiima, A., Basalirwa, C.P.K., Majaliwa, J.G.M., Otim-Nape, W., Okello-Onen, J., Rubaire-Akiiki, C., Konde-Lule, J. and Ogwal-Byenek, S., 2013. Nature and dynamics of climate variability in the Uganda cattle corridor. *African Journal of Environmental Science and Technology*, *7*(8), pp.770-782.

Nsabimana, A. and Li, P., 2023. Hydrogeochemical characterization and appraisal of groundwater quality for industrial purpose using a novel industrial water quality index (IndWQI) in the Guanzhong Basin, China. *Geochemistry*, *83*(1), p.125922.

Okeke, T., & Ndububa, O. 2019. An Overview of the Design Principles of Drinking Water Chlorination. Masters Dissertation submitted to Federal University Oye-Ekiti Institutional Repositoryhttp://repository.fuoye.edu.ng/handle

Ondieki, C.M., 2015. Aspects of water quality and water pollution control in vulnerable environments. *Journal of Geography and Earth Sciences*, *3*(2), pp.83-93.

Onyutha, C. and Kwio-Tamale, J. C. 2022. Modelling chlorine residuals in drinking water: a review. *International Journal of Environmental Science and Technology*, pp.1-18.

Oxfam International (2022). The life of South Sudanese refugees in Uganda on hold: Beatrice's story https://www.oxfam.org/en/life-south-sudanese-refugees-uganda-hold-beatrices-story

Packiyam, R., Kananan, S., Pachaiyappan, S. and Narayanan, U., 2016. Effect of storage containers on coliforms in household drinking water. *International Journal of Current Microbiology and Applied Sciences*, *5*(1), pp.461-477.

Paul, J. and Criado, A.R., 2020. The art of writing literature review: What do we know and what do we need to know?*International Business Review*, *29*(4), p.101717.

Pichel, N., de Souza, F.H., Sabogal-Paz, L.P., Shah, P.K., Adhikari, N., Pandey, S., Shrestha, B.M., Gaihre, S., Pineda-Marulanda, D.A., Hincapie, M. and Luwe, K., 2023. Field-testing solutions for drinking water quality monitoring in low-and middle-income regions and case studies from Latin American, African and Asian countries. *Journal of Environmental Chemical Engineering*, *11*(6), p.111180.

Pichel, N.,Vivar, M., and Fuentes, M. 2019. The problem of drinking water access: A review of disinfection technologies with an emphasis on solar treatment methods. *Chemosphere*, *218*, 1014-1030.

Pickering, A.J., Davis, J., Walters, S.P., Horak, H.M., Keymer, D.P., Mushi, D., Strickfaden, R., Chynoweth, J.S., Liu, J., Blum, A. and Rogers, K., 2010. Hands, water, and health: fecal contamination in Tanzanian communities with improved, non-networked water supplies. *Environmental science & technology*, *44*(9), pp.3267-3272.

Radjenovic, J. and Sedlak, D.L., 2015. Challenges and opportunities for electrochemical processes as next-generation technologies for the treatment of contaminated water. *Environmental science & technology*, *49*(19), pp.11292-11302.

Rahaman, K.S., Ramos, S., Harter, M. and Mosler, H.J., 2022. Determination of psychosocial factors of drinking chlorinated water to design behavior change interventions in Rohingya camps in Bangladesh. *The American Journal of Tropical Medicine and Hygiene*, *106*(4), p.1126.

Rodrigues, A. C. 2022. Comparison of commercial disinfectants and an in loco-produced solution: free residual chlorine decay in human supply waters. *Water Supply*, *22*(3), 2695-2706.

Rufener, S., Mäusezahl, D., Mosler, H.J. and Weingartner, R., 2010. Quality of drinking-water at source and point-of-consumption—drinking cup as a high potential recontamination risk: a field study in Bolivia. *Journal of health, population, and nutrition*, *28*(1), p.34.

Rutakumwa, R., Mugisha, J. O., Bernays, S., Kabunga, E., Tumwekwase, G., Mbonye, M. and Seeley, J., 2020. Conducting in-depth interviews with and without voice recorders: a comparative analysis. *Qualitative Research*, *20*(5), pp. 565-581.

Safe Water Drinking Foundation. 2017. Chlorination. https://www.safewater.org/fact-sheets-1/2017/1/23/what-is-chlorination.

Schraft, H. and Watterworth, L.A., 2005. Enumeration of heterotrophs, fecal coliforms and Escherichia coli in water: comparison of 3M™ Petrifilm™ plates with standard plating procedures. *Journal of microbiological methods*, *60*(3), pp.335-342.

Schumacher, A.J., Lingle, C.K., Silbernagel, K.M. and Thompson-Strehlow, L., 2022. Validation of the 3M™ Petrifilm™ coliform count plate for enumeration of coliforms in bottled water: AOAC performance tested method SM 082101. *Journal of AOAC International*, *105*(3), pp.866-875.

Sheikhi, R., Alimohammadi, M., Askari, M. and Moghaddasian, M. S., 2014. Decay of free residual chlorine in drinking water at the point of use. *Iranian journal of public health*, *43*(4), 535–536.

Sikder, M., Daraz, U., Lantagne, D. and Saltori, R., 2018. Effectiveness of multilevel risk management emergency response activities to ensure free chlorine residual in household drinking water in Southern Syria. *Environmental science & technology*, *52*(24), pp.14402-14410.

Sikder, M., Mirindi, P., String, G. and Lantagne, D., 2020. Delivering drinking water by truck in humanitarian contexts: results from mixed-methods evaluations in the Democratic Republic of the Congo and Bangladesh. *Environmental Science & Technology*, *54*(8), pp.5041-5050

Srivastav, A. L., Patel, N., & Chaudhary, V. K. (2020). Disinfection by-products in drinking water: Occurrence, toxicity and abatement. *Environmental Pollution*, *267*, 115474.

Staller, K. M., 2021. Big enough? Sampling in qualitative inquiry. *Qualitative Social Work*, *20*(4), pp. 897-904.

Steele, A. and Clarke, B., 2008. Problems of treatment process selection for relief agency water supplies in an emergency. *Journal of water and health*, *6*(4), pp.483-489.

Stocker, A. and Mosler, H.J., 2015. Contextual and sociopsychological factors in predicting habitual cleaning of water storage containers in rural Benin. *Water Resources Research*, *51*(4), pp.2000-2008.

Suthar, S., Sharma, J., Chabukdhara, M. and Nema, A.K., 2010. Water quality assessment of river Hindon at Ghaziabad, India: impact of industrial and urban wastewater. *Environmental monitoring and assessment*, *165*, pp.103-112

The Economist 2018 April 21. Refugees need not be a burden, if they are allowed to work https://www.economist.com/international/2018/04/21/refugees-need-not-be-a-burden-if-they-are-allowed-to-work

UN Women 2022 June 11.First Person: The South Sudanese refugee helping others through trauma https://news.un.org/en/story/2022/06/1119582

UNHCR 2017 February 23. New refugee settlement opens in Uganda as thousands of South Sudanese continue to flee every day. https://reliefweb.int/report/uganda/new-refugee-settlement-opens-uganda-thousands-south-sudanese-continue-flee-every-day.

UNHCR 2019 June 1. Pagirinya Settlement HLP Factsheet 2019 https://data.unhcr.org/en/documents/details/71923

UNHCR 2021a. What is a refugee? Retrieved on 10 November 2022 from https://www.unhcr.org/what-is-a-refugee.html.

UNHCR 2021b. Refugee data finder. Retrieved in 16 December 2022 from https://www.unhcr.org/refugee-statistics/.

United States Environmental Protection Agency. 2015. Quick Guide To Drinking Water Sample Collection. https://www.epa.gov/sites/default/files/2015-11/documents/drinking_water_sample_collection.pdf

Vargas, T. F., Baía, C. C., Machado, T. L. D. S., Dórea, C. C., & Bastos, W. R. 2021. Decay of free residual chlorine in wells water of Northern Brazil. *Water*, *13*(7), 992.

Wang, A. Q., Lin, Y. L., Xu, B., Hu, C. Y., Gao, Z. C., Liu, Z., ... and Gao, N. Y., 2018. Factors affecting the water odour caused by chloramines during drinking water disinfection. *Science of the total environment*, *639*, pp.687-694.

Water, Engineering and Development Centre. 2017. Water Sampling. https://wedc-knowledge.lboro.ac.uk/resources/booklets/G034-Water-sampling-online.pdf

WHO 2011 a. Guidelines for drinking water quality. WHO chronicle, 38, 104-108

WHO 2011b. Guidelines for drinkin water quality. WHO.

Wilson, R. E., Stoianov, I., & O'Hare, D. (2019). Continuous chlorine detection in drinking water and a review of new detection methods. *Johnson Matthey Technology Review*, *63*(2), 103-118.

Winchester, C.L. and Salji, M., 2016. Writing a literature review. *Journal of Clinical Urology*, *9*(5), pp.308-312.

World Health Organization (2019). WATA-Standard: WHO scheme to evaluate households to evaluate water treatment technologies. Geneva: WHO.

Worldometer 2023. Countries in the world by population in 2023. https://www.worldometers.info/world-population/population-by-country/

Wu, H., & Dorea, C. C. 2020. Towards a predictive model for initial chlorine dose in humanitarian emergencies. *Water*, *12*(5), 1506.

Wu, H., & Dorea, C. C. 2021. Evaluation and application of chlorine decay models for humanitarian emergency water supply contexts. *Environmental Technology*, 1-10.

Wu, H., and Dorea, C. C., 2022. Evaluation and application of chlorine decay models for humanitarian emergency water supply contexts. *Environmental Technology*, *43*(21), pp.3221-3230.

Yates, T., Allen, J., Leandre Joseph, M. and Lantagne, D., 2017. *WASH interventions in disease outbreak response*. Oxfam.

Yates, T., Vujcic, J.A., Joseph, M.L., Gallandat, K. and Lantagne, D., 2018. Efficacy and effectiveness of water, sanitation, and hygiene interventions in emergencies in low-and middle-income countries: a systematic review. *Waterlines*, pp.31-65.

Appendices

Appendix A: Questionnaire for Households

Dear respondent, my name is Dithan Mukiibi, a student at Uganda Christian University, Department of Engineering and Environment pursuing a Master of Science Degree in Water and Sanitation Degree. I am undertaking a research study titled ***"Assessment of effectiveness of chlorination and decay of residual chlorine at point of use in refugee settlements in Uganda: The case of West Nile".*** Your participation in this survey is voluntary as there won't be any form of financial benefits extended to you. The research study is guided by Uganda Christian University research code of ethics and integrity and therefore responses given will only be reserved for academic purposes. Thank you very much for time.

Do you agree to participate in this study voluntarily?

Yes ☐ No ☐

a- Proceed with the interview
b- Please don't proceed with the interview

……………………………… ……………………………………

Signature/Thumb print of respondent Date……………………………

Section A: Background Information

Questionnaire code: …… Date of interview: D …. M …. Y ……...

Interviewers' name: ……………………………………………..

Time started: ………. Time ended: ………

Ward... …………………

Date checked: D ….. M …. Y …….

Checked by: …………………………………

Data entrant: ……………………………………..

SECTION B: Socio – Demographic Characteristics

1: Age: ……

2: Marital status (Tick option): 1=Married 2=Divorced 3=Widowed 4=Never married

5=Other (specify) ……………………………………….

3: How many people live in your household (yourself, spouse, children, other

relatives, lodgers & servants)?………………

4: What is the total number of children that you have? ……………………………….

5: What is the main occupation of the household head? (Tick) 1=Farm 0=Non-farm

SECTION C: Water collection, storage and use in the household

6. What amount of water do you need per day______liters?
7. How long is the water tap from your house?................Metres

8. Who collects water that you use in your household? a) Father b) Mother c) children d) other house member e) All of us

9. Which carriage units or devices do you use?

a) Jerry cans b) Saucepans c) Pots d) Other devices (Please specify…)

10. Where did you acquire the carriage devices from?

a) Bought from market b) Rendered labor in exchange c) Donation d) Picked from a garbage collection site e) Inherited from a departing household

11. Do the carriage devices have protective covers?

1) Yes b) No

12. If Yes, when do you use these covers?

13. If No, what alternatives do you use to protect the water from foreign materials?

14. Do you have any water storage devices in the house?

1) Yes 2) No

15. If yes, which of the following devices do you use?

a) Big saucepan b) Water drum c) Big jerrycans d) Empties of big water bottles e) Any other (Please specify….)

16. What do you use to draw water from this storage device?

a) A small jerry can b)A water jug c) A saucepan d) Cup e) Big bowl e) Any other (Please specify).

17. How often do you clean the containers for collecting and storing water?

a) Weekly b) Once in a fortnight c) Once a month d) every 6 months e) Once a in a year f) Any other (Please specify….)

18. How long is water stored in your house before it is used off?

a) Less than 24 hours b) 24-48 hours c) More than 48 hours

19. Do you transfer collected water between the containers?

1) Yes 2) No

If Yes, what makes you to transfer water between containers?

SECTION E: Best practices for improving storage conditions for treated water in refugee settlements

With a tick (√), give your opinion to the following statements assessing the possible strategies for improving water quality management at household level in the this settlement using the following scaling: 1=Strongly Disagree, 2=Disagree, 3= Undecided, 4= Agree, 5= Strongly Agree

S/No	Statements	1	2	3	4	5
1.	Sensitizing the households on safe water storage and handling at point of use is important					
2.	WASH clubs in the refugee settlements are capable of improving water and sanitation management at household level					
3.	As far as I am concerned, establishing a WASH committee comprising all agency staff would improve water quality management in households					
4.	Supporting us with water collection and storage devices would equally improve the levels of water quality in my household					
5.	Increasing on numbers of taps nearby would also reduce on numbers of days or weeks for storing reserve water					

In what other ways do you think you can be helped to ensure that the quality of water stored and used by household is improved?

……

……

……

……

Thank you for participating in the study

Appendix B: Interview guide for Settlement WASH officers

1. Gender
2. Number of years working in the settlement
3. What is your highest education qualification?
4. What is your assessment of the practices followed by households in this settlement regarding collection, storage and use of water?
5. Why are community members more inclined to the practices that you have just mentioned?
6. Do you think these practices have an impact on the quality of treated water accessed from the distribution points?
7. If Yes, briefly explain how the practices that you have mentioned affect the quality of treated water?
8. Do you carry out any sensitization and mobilization campaigns to educate the community about management of quality of water at points of use?
9. If Yes, how often do you do so?
10. Who else apart from you is engaged in the sensitization?
11. If No, why have you failed to organize the mobilization and sensitization campaigns?
12. How can the quality of water in hand dug wells be improved**?**

Thank you for your participation

Appendix C: Observation Checklist

1. State of hygiene around the home
2. Outside appearance of the water collection devices in the household
4. Cleanliness of the water collection devices
5. Hygiene of the persons drawing water from the storage devices
6. Methods used to draw water from storage containers

Appendix D: Transmittal Letter from UCU

UGANDA CHRISTIAN UNIVERSITY

A Centre of Excellence in the Heart of Africa

FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY

Department of Engineering and Environment

13th Febuary 2023

TO WHOM IT MAY CONCERN

Dear Sir/Madam;

RE: INTRODUCTION LETTER FOR DITHAN MUKIIBI, REG. RM17M45/004

This letter is to introduce the above-named student of Uganda Christian University who is pursuing a Master of Science in water and sanitation.
The Master of Science in water and sanitation at Uganda Christian University (UCU) is a comprehensive program that provides professionals with a focus on water and sanitation. Additionally, students are prepared through courses such as integrated water resources management, Environmental Impact Assessment, scientific writing, communication skills, and project management to be able to work in multi-disciplinary environments.

The program trains skilled, versatile, professional, and ethical individuals for the national and international workplace by providing training in planning and design, construction supervision, operation and maintenance, and evaluation and monitoring of relevant engineered interventions for a safe, healthy and sustainable environment. Industrial, field, and design experience related to Environmental Data Collection and Management, Environmental Quality Monitoring and Control, Waste Management and Disposal, Water Quality Management, Environmental Impact Assessment, and auditing, is relevant to the training of the student.

We recommend to you the above student for assistance and highly appreciate your assistance in this matter.

Sincerely,

Uganda Christian University
13 FEB 2023
ENGINEERING & ENVIRONMENT

....

Grace Kesande Tusubira (Mrs.)

Administrative Assistant

Faculty of Engineering, Design and Technology

A Complete Education for A Complete Person

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UGANDA CHRISTIAN UNIVERSITY

SCHOOL OF RESEARCH & POSTGRADUATE STUDIES

DISSERTATION CORRECTION COMPLIANCE REPORT BY THE CANDIDATE (POST VIVA FORM)

Date: 7 April 2025

Name of Candidate: Dithan Mukiibi. **Reg. No:** RM17M45/004

Title of Dissertation: ASSESSMENT OF EFFECTIVENESS OF CHLORINATION AND FREE RESIDUAL CHLORINE DECAY AT POINT OF USE IN REFUGEE SETTLEMENTS IN UGANDA: THE CASE OF WEST NILE

SN	COMMENTS BY VIVA VOCE PANNEL	ACTION TAKEN	INDICATOR
1	The title has chlorine decay which wasn't brought out clearly. Don't use decay if you have not done any tests to determine it	Title has been tweaked from "Assessment of the effectiveness of chlorination and decay of residual chlorine at point of use in refugee settlements in Uganda; case of West Nile" to "Assessment of the effectiveness of chlorination and free residual chlorine decay at point of use in refugee settlements in Uganda; case of West Nile"	Cover page
2	Give a proper definition of chlorine	Definition is provided	Page 3

3	Please don't use the word experiment. Use the word measurements. Don't use wrong words	Suggestion adopted. The word measurement is used instead of experiment	Entire thesis
4	You cannot sterilize the sample containers using distilled water	Sterilization done in an autoclave	Page 26
5	In regards to the water supply chain, contamination can happen at source storage. Did you do any test of the outlet or the swamp	Measurements conducted at source points. Results are shown in Table 4.3	Page 41 and 42
6	What was the source of water before contamination?	Borehole and shallow well	Page 40
7	Be clearer about where the contamination began from, the taps, tanks, and trucks that transport the containers used for drinking.	Swab test results for taps at POD were negative. No contamination detected	Page 48
9	Where are the results in households?	Results presented in Tables 4.2, 4.8 and 4.9	Pages 39, 52, 53
10	Did you analyze the causes of contamination and did you follow these up from point of use?	Causes of contamination at POU established using multiple logistic regression	Page 52
11	What was your sample and what guided it? What were the numbers associated to these?	Sampling and sample size is indicated in Chapter 3	Page 24

12	Analyse the variance, external factors that influence contamination	ANOVA results computed and included in the thesis	Page 53
13	Quality of water at point of use	Results of water quality at POU are shown by Mann Whitney U test	Page 51
14	Combine results and the discussion	Suggestion taken	Page 37
15	Results should inform your conclusion and recommendations	Done as advised	Page 58

Dithan Mukiibi **Mr. Bernard Twinomugisha**

Candidate's Name Signature 07/04/2025 Supervisor's Name Signature 7/4/2025