DRINKING WATER QUALITY AND HUMAN DIMENSIONS: A CASE STUDY OF THE 2017–2018 CHOLERA OUTBREAK IN KARONGA, MALAWI

PRINCE KAPONDA

A THESIS SUBMITTED TO THE FACULTY OF ENVIRONMENTAL SCIENCES, DEPARTMENT OF WATER RESOURCES MANAGEMENT AND DEVELOPMENT IN FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN WATER RESOURCES MANAGEMENT AND DEVELOPMENT

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DECLARATION

I hereby declare that this thesis titled “Drinking Water Quality and Human Dimensions: A Case Study of the 2017–2018 Cholera Outbreak in Karonga, Malawi” has been written by me and is a record of my research work. All citations, references, and borrowed ideas have been duly acknowledged. It is being submitted in fulfilment of the requirements for the award of the Degree of Master of Science (MSc) in Water Resources Management and Development of the Mzuzu University. None of the present work has been submitted previously for any degree or examination in any other University.

Parts of the materials presented in this thesis have been submitted for publication in the Journal of Water Supply.

Name of Student: PRINCE KAPONDA

Signature: ____________________________ Date: ________________________

CERTIFICATE OF APPROVAL

The undersigned certify that this thesis is a result of the author's own work, and that to the best of our knowledge, it has not been submitted for any other academic qualification within the Mzuzu University or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by thesis was demonstrated by the candidate through an oral examination held on: 19 November 2019.

Signature: ____________________________ Date: _____________________________

Major Supervisor: Dr. R. Holm

Signature: _____________________________ Date: ______________________________

Co-supervisor: Eng. E. Mtonga

ABSTRACT

The aim of this study was to assess drinking water source quality and human dimensions: a case study of the 2017–2018 cholera outbreak in Karonga, Malawi. The study analysed 120 drinking water samples using standard methods and survey data linked to 236 cholera patients. Kruskal-Wallis One-way Analysis of Variance (ANOVA); One sample T-test, Mann Whitney test, Chi-square test and descriptive statistics were used to analyse data. Results showed that many samples (98/120) met the Malawi Bureau of Standards (MBS) criteria for thermotolerant coliforms of 50 cfu/100 ml, while half (60/120) met the more stringent World Health Organization (WHO) criteria of 0 cfu/100 ml. Microbiological quality of water was in the range of 0 to >200 cfu/100ml. Majority of the samples were within MBS limits for pH (93%) and turbidity (89%). All the samples were within MBS and WHO limit for Total Dissolved Solids (TDS) while majority of the samples were within WHO limit for EC (91%). Physico-chemical quality results were in the following ranges: 6 - 9.98 (pH); <5 ->500 JTU (turbidity); 18.8 - 1393µS/cm (electrical conductivity); 9.40 - 696.5 mg/l (TDS) and 0.02 - 0.70 PSU (salinity). About 70% of respondents reported to have treated their water, and knowledge of prevention, transmission and treatment of cholera was generally high (67%, n = 236). A few patients (38%, n = 32) who had poor drinking water source quality (>200cfu/100ml) reported feeling no risk of contracting cholera in the future. There was a significant correlation (p = 0.046) between the number of assets owned by a household and water treatment practice at household level (r = -0.148). The increase in number of households which did not practice water treatment corresponded with a decreased in number of assets. To control and eliminate the risk of cholera there is a need to promote household water treatment using chlorine, behavioural change

interventions accounting for social and cultural norms and provision of potable water sources for the 22 geographic areas which had drinking water of poor quality.

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My study would not have been a success without the support and encouragement from my dear wife Mrs. Christina Kaponda and the entire Kaponda family, my pastor (Mr. E. Jabu), colleagues at work, and classmates.

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CFR	Case Fatality Rate
CFU	Colony Forming Unit
DFID	Department of International Development
EC	Electrical Conductivity
GPS	Global Positioning System
HFA	Hyogo Framework for Action
HSA	Health Surveillance Assistant
HWT	Household Water Treatment
HWTS	Household Water Treatment and Safe Storage
JTU	Jackson Turbidity Unit
MBS	Malawi Bureau of Standards
NDRMP	National Disaster Risk Management Policy
NEHP	National Environmental Health Policy
NEP	National Environmental Policy
NSO	National Statistical Office
NSP	National Sanitation Policy

NTU	Nephelometric Turbidity Units
NWP	National Water Policy
NWRA	National Water Resources Authority
OCV	Oral Cholera Vaccine
ODK	Open Data Kit
PSU	Practical Salinity Units
SDG	Sustainable Development Goal
SFDRR	Sendai Framework for Disaster Risk Reduction
SHARE	Sanitation and Hygiene Applied Research for Equity
SPSS	Statistical Package for Social Scientists
TA	Traditional Authority
TDS	Total Dissolved Solids
UNICEF	United Nations Children's Fund
USD	United States Dollar
WASH	Water Sanitation and Hygiene
WHO	World Health Organisation

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CHAPTER 1: INTRODUCTION

This chapter presents the background of the study outlining the aims, hypotheses of the study, justification of the study, ethical considerations and study limitations.

1.1 Background

Clean water is conducive for good health, indirectly promoting economic growth and contribute to poverty reduction in a society (World Health Organisation (WHO) & United Nations Children's Fund (UNICEF) 2017). Assessment of water scarcity globally in 2016 revealed that 4 billion people were under severe water scarcity problems for more than a month each year (Mekonnen & Hoekstra 2016). Further, about 0.5 billion people globally encounter drinking water scarcity problems throughout the year (Mekonnen & Hoekstra 2016). According to WHO & UNICEF (2017), in 2017, 6.8 billion people globally were using basic drinking water sources which are close to the users and far from potential contaminants (including fecal matter and chemicals). The United Nation's Sustainable Development Goal (SDG) number six aims at ensuring access to clean water and sanitation for all by 2030. About 1.4 billion people globally (21%) have access to basic water sources which are described to be located within a walking distance of 30 minutes round trip and 435 million people use water collected water from unprotected wells (WHO & UNICEF 2017). Improved sanitation facilites are described as those which hygienically protect a human being from being in contact with feces. These facilities are categorised into limited (shared), basic and safely managed (not shared) facilities (WHO & UNICEF 2017). Globally, about 68% of the population have access to basic sanitation facilities (WHO & UNICEF 2017).

Consumption of contaminated water among other hazards is linked to transmission of preventable diseases like diarrhoea, cholera, dysentery, polio, hepatitis A and typhoid. *Vibrio cholera* infection is a serious global health problem, with sub-Saharan Africa countries being one of the most affected areas (Mandal, Manda & Pa 2011; Bwire et al. 2016). Globally, about 829, 000 deaths are reported each year due to diarrhoeal diseases emanating from consuming water of poor quality, sanitation and hygiene (WHO & UNICEF 2017). In a fight against risks of diarrhoeal diseases it has been reported that understanding of community perceptions related to risks and cultural practices play a vital role (Ngwa et al. 2017).

Malawi has a population of about 17.6 million people reported in the recent population census (National Statistical Office 2019). Nationally, 85% of the population in Malawi have access to an improved drinking water sources, with about 3 million people continuing to lack access (NSO 2019). Access to basic sanitation in Malawi is at 60% (NSO 2019). Cholera and other diarrhoeal diseases are common due to poor transportation and storage practices of water and poor sanitation and hygiene practices at household level (WHO & UNICEF 2017). Malawi is hit by cholera outbreaks yearly in the rainy season period (Msyamboza et al. 2014). The greatest number of cholera cases (33,546 cases and 968 deaths, case fatality rate of 2.3%) in Malawi occurred in 2001 – 2002 season (Msyamboza et al. 2014).

Access to an improved drinking water source in the study district (Karonga) is reported at 90%, higher than the national average (85%), while improved sanitation facilities is at 47.5%, lower than the national average (NSO & ICF2017). In the 2017/2018 rainy season, 13 districts of Malawi (Blantyre, Chikwawa, Dedza, Dowa, Karonga, Kasungu, Likoma, Lilongwe, Mulanje, Nkhatabay, Rumphi and Salima) reported cholera cases with a total of 939 cases and 32 deaths of which Karonga District in northern Malawi had the highest cholera incidence rate as a portion of the population (Government of Malawi 2018). There were 347 reported cholera patients in the outbreak between November 2017 and March 2018 in Karonga District (Government of Malawi 2018). A total of 7 deaths were recorded, representing a cholera Case Fatality Rate (CFR) of 2.02%, compared to WHO recommended <1% CFR. During the outbreak, no drinking water surveillance was conducted. The main reported cause of cholera outbreak in the district is drinking of unsafe water, whose poor quality is worsened by flooding situations. According to a report by the district health office, many people lack safe sanitation and drink unsafe water from the rivers, wells and Lake Malawi (Government of Malawi 2016). The most affected in Karonga District are informal settlements in flooding zones (Manda & Wanda 2017).

1.2 Problem statement

Cholera outbreaks in Karonga District have been particularly linked to poor sanitation and water supply (Manda & Wanda 2017). The extent of these cholera patients who are drinking unsafe water and why they may be drinking unsafe water is not available from literature accessed. Holm, Kunkel & Nyirenda (2018) argued that there is limited groundwater quality information and very few laboratory services in the northern part of Malawi including Karonga. Further, that study highlights that the following constituents need further investigation about possible human health risks: *Escherichia coli* and/or thermotolerant coliform bacteria, and turbidity because nitrate and pH are the most common water quality data available for the Northern Region specifically Karonga District. Cholera studies in Malawi have been done mostly in the Southern part of the country (Msyamboza et al. 2014; Khonje et al. 2012). However, in the Northern Region, specifically Karonga District, while non-peer reviewed reports on the number of cholera cases are available from the Ministry of Health, these are lacking a link to water quality data and human dimensions' information for areas which were affected by 2017/18 cholera season as no drinking water surveillance was conducted during the outbreak. Sir John Snow in 1849 was able to link contaminated water with cholera outbreaks in London. However, in the absence of water quality surveillance data after the 2017 – 2018 cholera outbreak, the dynamics and synergies of cholera incidence, drinking water quality and human dimensions are not well documented for Karonga. Therefore, the current study was conducted to assess drinking water quality and human dimensions of cholera affected households in Karonga District, Malawi.

1.3 Aims of the study

1.3.1 Main objective

The main objective of the study was to assess drinking water quality and human dimensions of cholera affected households of the 2017 – 2018 season in Karonga, Malawi.

1.3.2 Specific objectives

The study specifically addressed the following objectives:

i). To determine microbiological (thermotolerant coliform bacteria) and physico-chemical quality (pH, temperature, turbidity, electrical conductivity, total dissolved solids and salinity) of water from main drinking water sources used by cholera affected households during the 2017 – 2018 cholera season.

ii). To investigate household point-of-use water treatment practices for the 2017 – 2018 cholera affected households.

iii). To assess the role of human demographics (risk perceptions, knowledge and socio-economic status) on cholera incidence during the 2017 – 2018 cholera season.

1.4 Research hypotheses

i). There is a significant difference in microbiological and physico-chemical quality of drinking water used by cholera affected households compared to the local and international standards.

ii). There is a significant association between water treatment practices, socio-economic status and type of water sources used by cholera affected households.

iii). There is a significant association between human demographics (risk perceptions, cholera knowledge and socio-economic status) and drinking water source quality.

1.5 Justification of the study

This study fills a gap on the knowledge and understanding of the current drinking water quality situation for the areas which were affected by the 2017/18 cholera season in Karonga District. This information will be useful to both the academic and development agencies as it will inform policy makers on appropriate action needed as well as provide further research bases in the Water Sanitation and Hygiene (WASH) sector in a fight against cholera outbreaks. Furthermore, published findings will benefit the global community as well as strengthen the already existing collaboration with partners working on cholera response.

1.6 Ethical consideration

The study sought approval from the Malawian Government, National Commission for Science and Technology protocol number P.07/18/291 (Appendix A) and Faculty of Environmental Science (Mzuzu University). Furthermore, study participants were provided with verbal consent in their language (Appendix B) before interviews and observations. The consent was emphasized to participants because they deserved to know that information obtained from them was to be treated as anonymous and would not be used for personal gains. This was done to ensure privacy and confidentiality of participants.

1.7 Study limitations

The study only considered suspected cholera cases, it was not a case-control study. Water samples were tested for thermotolerant coliforms, not *V. cholera*. Cholera patient cases self-reported to the health facility for treatment, and other patients may have refused to go to the health centre due to cultural beliefs or refusal to take medicine. Over 100 cases in the district could not be traced; most of these were mobile fishers or those not known by the area government health workers, which may provide one of the highest risk population groups to prevent the recurrence of cholera. The study was conducted soon after the cholera outbreak, and in some cases the drinking water conditions may not be representative. Water quality in this study may have been better than during the outbreak, as this study was conducted in the dry season. In addition, respondents do not necessarily use only one water source for drinking water. Whilst they may have identified their main source, it is likely that many drank from rivers and streams whilst out travelling or working, demonstrating the need to focus on behaviour change interventions. As well, the survey was conducted after each of the patients had cholera, therefore their knowledge and awareness of cholera prevention, transmission and symptoms is likely to have been improved whilst receiving treatment and better than the general population.

CHAPTER 2: LITERATURE REVIEW

This chapter presents known literature related to the study objectives. The chapter also includes subsections on national framework in Malawi related to water quality and a conceptual framework for the study.

2.1 National Legislation and Policies related to water quality and cholera control

The various legal frameworks that govern water resources and its quality in Malawi are as follows: Malawi Government Water Resources Act 1969 which provides the main regulatory framework for water resources management; Malawi Government Water Works Act 1995 which is the main authority on water supply and water borne sanitation delivery services. The government of Malawi also launched Public Health Act 1968 after independence; and Environment Management Act 1996. Chiluwe and Nkhata (2014), found that the water resources act of 1969 has not been instrumental in creating the enabling environment for good water governance. Further, there is lack of punitive measures against those who cause substantial water pollution (Chipofya, Kainja & Bota 2012). However, Chiluwe and Nkhata (2014) acknowledged the good development on the introduction of national water policy of 2005 which is instrumental in contributing to good water governance through its various provisions if properly implemented. The Water Resources Act of 2013 facilitated the establishment of the National Water Resources Authority (NWRA) which is an entity intended to provide advice on water resources policy and implement regulatory functions. The national legal framework contribute to addressing cholera outbreaks by ensuring that policies are enforced and where there is non-compliance appropriate fines are paid.

Policy frameworks which are related with cholera risk elimination and control in Malawi include: National Water Policy (NWP); National Sanitation Policy (NSP); National Environmental Policy (NEP), National Environmental Health Polity (NEHP) and National Disaster Risk Management Policy (NDRMP). The water policy operates with a vision of 'Water and Sanitation for all, always' with an overall goal of sustainable management and utilisation of water resources, in order to provide water of acceptable quality and of sufficient quantities, and ensure availability of efficient and effective water and sanitation services that satisfy the basic requirements of Malawians (Government of Malawi 2005). The policy (NWP) has specific goals on water quality and pollution control; and rural water services among others. It specifies that the ministry responsible for health has the role of monitoring and providing guidance on drinking water quality and provision of appropriate interventions to prevent the prevalence of water related disease including cholera. The National Environmental Policy also stipulates in one of its guiding principles that all people should have access to clean potable water in order to reduce the incidence of water borne diseases like cholera and reduction of the time devoted by individuals to water collection (Government of Malawi 2004). Recently the government of Malawi introduced the National Environmental Health Policy with support from WHO to guide the implementation of environmental health interventions which will help to mitigate the risk factors and reduce the sanitation and hygiene related disease burden which is high in the country (Government of Malawi 2018). The overall goal of the National Sanitation Policy is to enhance the reduction of waterborne and sanitation related diseases (including cholera) in Malawi (Government of Malawi 2008). The policy (NSP) operates under one of the guiding principles that every household should have a sanitation facility to reduce the potential of facilitating the transmission of water and sanitation related diseases like cholera. Despite having national water and sanitation policies, implementation is still a challenge as the water resources act being used is very old and does not capture the policies entirely (Chiluwe & Nkhata 2014). The recently introduced 2018-2024 National Sanitation and Hygiene Strategy aims to re-align Malawi's efforts in attaining universal, sustainable, and equitable access to sanitation and hygiene, and the elimination of open defecation as reflected in the Sustainable Development Goals (SDG 6: Ensuring availability and sustainable management of Water, Sanitation for all) (Government of Malawi 2018). The Government of Malawi enacted the National Disaster Risk Management Policy in 2015 to create an enabling framework for the establishment of a comprehensive disaster risk management system for Malawi (Government of Malawi 2015). The disaster risk management policy is linked to water resources act, national water and policies among others. The priority areas of the policy were set to help meet the commitment of the outgoing Hyogo Framework for Action (HFA) (2005-2015) which was replaced by the Sendai Framework for Disaster Risk Reduction (SFDRR) (2015-2030).

2.2 Microbiological quality of drinking water and cholera incidence

The quality and safety of water for human consumption is defined by its physical, chemical and biological characteristics relative to set standards. Sir John Snow was the first scientist to link outbreaks of cholera to poor water quality (Snow 1855). *Escherichia coli* and/or thermotolerant (faecal) coliform bacteria are recommended by various standards including WHO guidelines as organisms to indicate faecal contamination (WHO & UNICEF 2017; WHO 2017; Leclerc et al. 2001; Tallon et al. 2005). This is so because over 95% of thermotolerant coliform bacteria isolated from drinking water is traced to originate from gut of living animals/humans which provides proof of faecal contamination. Hodge et al. (2016) found an increased risk of diarrhoea with increased levels of thermotolerant coliform bacteria in drinking water, which shows an association between fecally contaminated water and diarrhoeal diseases. Similarly, Cabral (2010) concluded that microbiological control of drinking water should be the norm everywhere and that microbiological analysis of drinking water be done by analysing the presence of *Escherichia coli* using culture methods. Jutla et al. (2013) noted that interaction of daily activities of people with fecal contaminated water is accelerated by heavy rains which destroy sanitary facilities, leading to cholera outbreaks.

The integrity of a water source is affected by the condition of its environmental surrounding. This includes: siting of the water source (within 30 m or far from potential contaminants); state of the constructed structures; abandoned or unused wells; and fencing/protection from human activities. Zin et al. (2015) note that the quality of water is associated with distances to latrines. In Karonga District, most households use pit latrines and remain unserved with regard to faecal sludge management and solid waste removal, and the local government has been unable to offer adequate coverage of sanitation services (Holm et al. 2018). This situation is similar to the Lake Chilwa bordering Districts (Zomba, Machinga and Phalombe) which are characterised by temporary fishing villages and prone to cholera outbreaks in the Southern Region of Malawi (Khonje et al. 2012).

Groundwater wells should be sited far (more than 30 meters) from potential contamination sources like pit latrines, sewage pits, grave yards, animal pens and dumping sites among others (Malawi Bureau of Standards 2005). The WHO drinking water guideline does not specify the exact distance on siting of well from potential faecal contaminants. Owoeye and Akinneye (2018) reported that well water sampled in their study (Ondo State, Nigeria) had greater coliform counts than the WHO recommended level (0 cfu/100 ml) for drinking water at an average distance of 17.6 m from sewage pits. Apart from siting groundwater sources at a recommended distance from potential pollutants, groundwater sources should be sited up-gradient from the potential sources of contamination as topography is one of the factors contributing to well water contamination (Schneider 2014; Owoeye & Akinneye 2018).

Drinking water sources which people use have varying water quality due to pollutant exposure. Those that are open, exposing the water to contact with air and other substances like faecal matter and chemicals, are more susceptible to biological contamination. Protected water sources are covered by stone work, concrete or other materials that prevent the entry of physical, chemical and biological contaminants (WHO & UNICEF 2017). Yet, protected water sources are not necessarily safe as there are other factors that influence the supply of quality drinking water (Seid et al. 2003). Shaheed et al. (2014), in a study on ‘water quality risks of improved water sources’ found that the microbial quality of improved water sources was not consistent at the point of consumption and attributed it to the mixing of water sources in the households; unsafe storage; handling practices; and inadequately treated piped water. Further, microbiological contamination in stored water is attributed to unhygienic water handling practices. Therefore, earthen pots storage facilities record lower coliform bacteria due to the narrow opening which makes access more difficult compared to polyethylene and mettalic containers (Akuffo et al. 2013).

Surface water is ranked at the bottom of the ladder in terms of improved water quality, while piped water into the household is at the top. Groundwater particularly from deep sources, may provide water of good microbiological quality (WHO & UNICEF 2017). This is because bacteria, protozoa, viruses and helminths are filtered from the water as it passes through the layers of soil and rock. However, groundwater can contain chemical contaminants.

There is community awareness of several hand pump options for the rural water supply in Northern Malawi which could allow communities to choose the type of hand pump model (Holm et al. 2017). However, the choice of a good water source is reported to be affected by a number of significant factors including: family size; number of rooms in a house; and location (urban/rural) (Rauf et al. 2015). According to Angoua et al. (2018), there is an association between socio-economic status and settlement characteristics and poor access to reliable water and sanitation in peri-urban settlements. Further, greater access to clean water has been shown to be associated with the presence of household head's wife at home and households headed by ever married persons, thereby highlighting the role of women in access to clean water in homes (Angoua et al. 2018; Irianti, Prasetyoputra & Sasimartoyo 2016; Kausar et al. 2011). Irianti et al. (2016) reported that there was a positive association between access to safe water source and having better sanitation facilities, household size and household wealth in Indonesia. This translates that households with good sanitation facilities (improved) have high likelihood of using improved drinking water sources compared to those having un-improved sanitation facilities. In terms on household size, they reported that an addition of a member to a household increased the likelihood of a household using an improved drinking water source. Further, in terms of wealth status, households with more wealth were found to be more likely to use improved drinking water sources.

2.3 Physico-chemical quality of water and cholera incidence

Vibrio cholera is a bacterium that is known to survive more than a week and 8 weeks in fresh and saline water respectively and can spread from one person to another through the faecal oral route (Todd, Lockwood & Sundar 2006). There is evidence that consumption of fish and fish products has been linked to cholera outbreaks which points to evidence that some fish species are symbiotic harbours of the cholera bacteria (Halpern & Izhaki 2017). The maximum growth of cholera bacteria is reported at salinity levels of 25000 ppm while 100 ppm or greater is required for it to survive one day and the optimum level of survival is in the range of 5000-30000 ppm (Singleton et al. 1982; Huq et al. 1984). Open water sources are a good environment for *V. cholera* survival as noted by Grant et al. (2015) who found salinity levels of non-drinking water sources (rivers) showed conditions for *V. cholerae* survial exist 7-8 days within the local aquatic environment while salinity levels of participant's drinking water sources were all below *V. cholerae* survival in coastal Bangladesh. Further, respondents showed preference for less salty drinking water which led to conclusion that there is avoidance of contaminated water sources in coastal Bangladesh and that no physical connections exists between river system and drinking water sources (Grant et al.2015). The WHO recomends a threshold of 200–300 mg/l for salinity in drinking water (WHO 2017).

For Karonga District, scarcity of drinking and groundwater water quality data makes it difficult to assess its risks on human health, as reported by Holm et al. (2018). Hydro chemical studies on the quality of groundwater in Karonga have shown varying concentrations of trace elements (Wanda, Gulula & Phiri 2013; Mapoma et al. 2016; Mapoma et al. 2017). There is no direct link of trace metals and cholera incindence. Along the North Rukuru river in Karonga, Mapoma et al. (2016) linked anthropogenic and industrial activities to levels of heavy metals and trace elements. The accumulation of polutants affects abundance of zooplanktons (copepods, rotifers and cladocerans) which were reported to be associated with cholera incidence in Bangladesh (Magny et al. 2011). According to Mapoma et al. (2017), carbonate dissolution, silicate weathering and cation exchange are the main geochemical control mechanisms. Further, anthropogenic activities and rock-water interaction are responsible for flouride and nitrate while dissolution/precipitation and pH control the levels of As, Fe and Mn. Wanda et al. (2013) found TDS levels of about 1000 ppm, within the limit of 2000ppm by MBS. Table 1 shows previous physico-chemical quality results for Karonga District.

Table 1: Physico-chemical quality results from previous studies in Karonga District

	pH	***Turbidity (JTU)***	***Electrical conductivity (µS/cm)***	***Total Dissolved Solids (mg/l)***	***Salinity (PSU)***
Manda & Wanda, (2017) (*n* = 27)	5.2 - 8.3	NA	NA	50 – 580	NA
Wanda et al. (2013)	6.3 - 8.10	NA	120 - 1730	50 – 950	NA
Mapoma et al. (2016) (*n* = 25)	6 - 7.1	Below detection limit to 23	105 - 930	52 – 468	NA
Mapoma et al. (2017) (*n* = 25)	6 - 7.1	0.1 to 23.0	213 - 1696	105 – 850	NA

	pH	*Turbidity (JTU)*	*Electrical conductivity (µS/cm)*	*Total Dissolved Solids (mg/l)*	*Salinity (PSU)*
MBS Standard [a]	6.0 - 9.5	25	3500	2000	NA
WHO Standard [b]	6 - 8.5	1	750	1000	NA

The turbidity of water is reported to be correlated with cholera incidence in that turbid water provides cholera causing bacteria a conducive environment for their survival (Khonje et al. 2012). Turbid river water was found to be directly associated with cholera incidence in Uganda (Ekello et al. 2019). Electrical conductivity, TDS and Salinity are related as they describe the saltiness of the water. The incidence of cholera in relation to saltiness of water is reported to be positive as reported in Bangladesh by Grant et. al (2015).

2.4 Water treatment and cholera outbreaks

It has been widely reported that communities which use untreated water as a source of drinking water are vulnerable to water borne diseases (Msyamboza et al. 2014; Khonje et al. 2012; Bompangue et al. 2008; Bimingham et al. 1997). Mohsin et al. (2013) linked contaminated drinking water in Bahawalpur, Pakistan to severe waterborne disease like cholera and suggested water treatment as a solution to ensure safety. Silver impregnated porous pot filters (SIPP) have the highest bacterial removal efficiency (99-100%) and the lowest are obtained by biosand filters (BSF) (20-60%) (Mwabi et al. 2011). Water treatment practices at household level is relevant even when water sources are protected as water quality can be affected at source, distribution and point of use (Budiyono et al. 2014; Kosamu et al. 2013). The problem of poor water quality at household level is also attributed to contaminated water storage facilities and utensils which are used to draw water for consumption and other uses (Kaonga et al. 2013). Common household water treatment and storage (HWTS) techniques in rural areas of Malawi include use of chlorine products and the more traditional way of boiling water and allowing it to cool while buckets with lids and clay pots are used for storing water (Mkwate, Chidya & Wanda 2017). Boiling is thought to be the best method for disinfection of drinking water in Burla, India (Pradhan et al. 2018). Benefits of water treatment are wide spread and crosscutting but require integration of behaviour change promotion and enhancing accessibility of products to more populations at risk (DuBois et al. 2010). Bivariate analysis by Li, Liu & BeLue (2018) shows a negative association between the nutritional status of children and HWT. Additionally, findings from the generalized simultaneous equation model demonstrate that HWT increases the probability of producing normal-weighted primary-aged children by 1.7%, while it decreases the probability of primary-aged children being thin by 2.5% and being severely thin by 1.7% in India. This study indicates that HWTS has the potential to advance the nutritional status of primary school-aged children in India (Li et al. 2018).

In developing countries, studies have shown that improvements in water quality through water treatment and good storage practices could lead to reduction in diarrhoea incidences in a community (Arnold & Colford 2007; Clasen et al. 2007; Fewtrell et al. 2005). Families who adopt measures to improve the drinking water quality at home are at lower risk of diarrheal diseases (Kausar et al. 2011).

Household water treatment burdens poor households and calls for interventions to support such groups with safe water (Shrestha et al. 2018). There is an association between the usage of water treatment products and use of water source with high turbidity while continuity of use of the chlorine products is correlated with accessibility of products (DuBois et al. 2010). Poverty incidence, depth and severity was lower for households who own certain assets as land, houses, cars, motorcycles and sewing machines in Akwa Ibom State, Niger Delta, Nigeria (Etim & Edet 2014). Further, low asset portfolio of households as noted by Etim and Edet (2014) calls for poverty reduction interventions which would increase the asset portfolio of rural households. Literate people and those in the wealthiest quintiles are more likely to chlorinate stored water (Freeman et al. 2009).

HWTS interventions may reduce the burden of disease in cholera outbreaks and the risk of disease transmission. Appropriate training for users and community health worker follow-up are necessary for use. Barriers to uptake of HWTS include taste and odour concerns, and facilitators include prior exposure, ease of use, and links to pre-existing development programming (Lantagne & Yates 2018). Crampton and Ragusa (2016) also found that majority of respondents believed that self-evaluation of drinking water's taste and appearance were sufficient measures to ensure safe consumption. Further research on local barriers and facilitators, HWT filters, scaling up existing development programs, program sustainability, integrating HWT and oral cholera vaccine, and monitoring in low-access emergencies is recommended (Lantagne & Yates 2018).

Higher rates of effective use of HWT have been reported to be associated with successful water treatment interventions in emergencies (Lantagne & Clasen 2013). According to Clasen (2015), effectiveness of HWTS can be optimised by ensuring that the method is microbiological; making it accessible to an exposed population; and securing their consistent and long term use.Faulty perceptions on water treatment, lack of knowledge about health hazards associated with drinking unsafe water, false sense of protection from locally available water, resistance to change in taste or odor of water and a lack of support from male members of the household were important factors impeding acceptance and long term use of water quality intervention in southern India (Francis et al. 2015). Some reports have shown no evidence of HWT protecting against diarrhoea where low compliance and modest reduction in water contamination have contributed to the lack of effect (Boisson et al. 2013).

2.5 Cholera and human dimensions

The updated global burden shows that more than 1 billion people are prone to cholera in countries where cholera is endemic, particularly concentrated in sub-Saharan Africa including Malawi (Ali et al. 2015; Gwenzi & Sanganyado 2019). Cholera risk factors apart from drinking contaminated water include: consumption of unrefrigerated leftover food; consumption of vegetables and fruits; and travelling behaviour (Moradi et al. 2016). Further, these cholera risks are reported to have a negative correlation to literacy level of an individual, use of safe water, and ownership of cell phones, and a positive correlation to unimproved sanitation (Ali et al. 2017). This translates on one hand that those who are literate, use safe water and wealthy are more likely to have a low risk of contracting cholera. On the other hand, findings by Ali et al (2017) suggest that households that are using unimproved sanitation facilities have a high risk of contracting cholera. Improvements in drinking water quality is one of the strategies towards cholera control. Access and use of safe drinking water is reported to be influenced by factors including perceived high saline water (Abedin et al. 2014). The problem of poor water quality is assumed to be prevalent in informal settlements where it is suggested to be the route of disease transmission (Rebaudet et al. 2013; Blanton et al. 2015; Manda & Wanda 2017). According to Manda and Wanda (2017), in Karonga District the risks of unsafe sanitation and poor drinking water quality are high among low income households. This is worsened by the limited capacity of the local government, and its failure to address the underlying causes of its incapacity, linked to devolution, weak urban planning and customary land tenure. The study by Talavera and Perez (2009) shows that low-income countries are more affected by cholera disease than countries with middle or high income and economic development is recommended as one of the important factors in the morbidity and mortality of cholera. The burden of cholera in sub-Saharan Africa (SSA) which mostly affects under five children and children in school going ages is attributed to cross-border cholera outbreaks which cholera actors have done little to eliminate and control (Bwire et al. 2016). There is need for clear guidelines (preventive measures, detection, monitoring and control) coordinating cholera stakeholders in order to eliminate the risks of the outbreaks in SSA (Bwire et al. 2016). The detection part requires sample collection and analysis by knowledgeable and trained personnel trained, compiling baseline data, and an effective risk presentation back to households to motivate behavioural changes (Holm et al. 2016). It has been reported (Bwire et al. 2017) that oral cholera vaccines could supplement water, sanitation and hygiene improvements in high-risk areas and populations in the prevention and control of cholera outbreaks. In Malawi, it is feasible and acceptable by communities to conduct a large-scale mass oral cholera vaccine (OCV) campaign within five weeks and OCV could be used as an additional measure in cholera hot spot areas like Karonga (Msyamboza et al. 2016). Mandal et al. (2011) also note that oral vaccines lower the number of resistant infections and represent an effective intervention measure to control antibiotic resistance in cholera. Additionally, Ujah et al.

(2015) note that cholera prevention, control and elimination could be achieved by promoting and facilitating access to social services including poverty reduction and education. Further, wrong perception and myth of cholera hinders acceptance and accessibility to launch effective operational response to affected communities during an outbreak and leads to delay in providing intervention and treatment during an outbreak (Ujah et al. 2015).

2.6 Conceptual framework

Type of water sources, integrity of water sources and water treatment are some of the factors which determine the quality of water. Further, other human dimensions like risk perceptions; knowledge of causes and transmission of diarrhoeal diseases like cholera; and socio-economic status also have an impact on drinking water quality which a household uses. All these factors in a way contribute to cholera incidence rates in an area.

Types of water sources are categorized into improved and un-improved by the WHO/UNICEF Joint Monitoring Programme (WHO & UNICEF 2017). "Improved" drinking water sources include: piped water into dwelling; piped water into yard/plot; public tap/standpipes; boreholes; protected dug wells; protected springs (normally part of a spring supply); rainwater collection and bottled water, if the secondary source used by the household for cooking and personal hygiene is improved (WHO & UNICEF 2017). Water sources that are considered as "Un-improved" are: unprotected dug wells; unprotected springs; vendor provided water; cart with small tank/drum; bottled water, if the secondary source used by the household for cooking and personal hygiene is unimproved; tanker-truck and surface water (WHO & UNICEF 2017).

The integrity of water sources is influenced by environmental factors surrounding the water source including proximity to pit latrines, septic tanks, graveyards or any other sanitary disposal facilities. Water sources that are not properly covered or do not protect from contact of water to pollutants may lead to poor drinking water quality due to contamination.

Drinking water treatment at point of use is the process that improves the quality of water to make it more acceptable for human consumption (Budiyonoet al. 2014; Kosamu et al. 2013). This involves removal of contaminants from raw water. Substances that are commonly removed during the process of rural water supply include: suspended solids, bacteria, algae, viruses, fungi, and minerals such as iron and manganese. Processes involved in removing contaminants include physical processes such as settling and filtration, chemical processes such as disinfection and coagulation and biological processes such as slow sand filtration (Farhaoui & Derraz 2016; Zouboulis & Katsoyiannis 2019).

The linkages of these factors are illustrated in Figure 1. The components which the study is focusing on have been shaded in green.

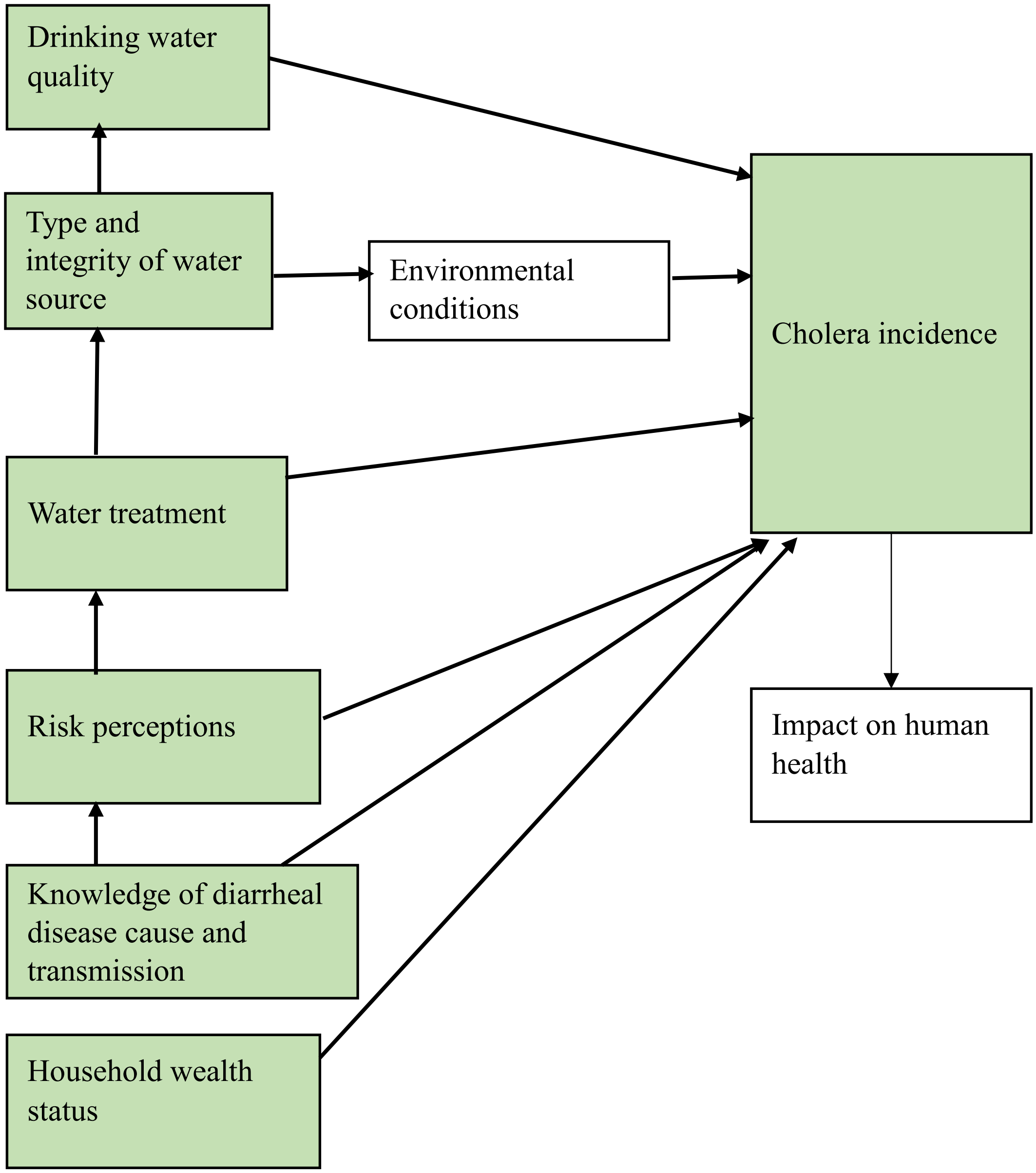

Figure 1: Conceptual framework for the study

CHAPTER 3: MATERIALS AND METHODS

This chapter outlines the data collection and laboratory analysis to gather data for the study and data processing procedures used. The chapter includes a description of the study area, research design, sampling framework, data collection, water sample collection and analysis, data analysis, and research dissemination strategy.

3.1 Study area

This study was conducted in the Northern region part of Malawi, Karonga District focusing on cholera cases for the 2017/18 cholera season. This district, as shown in Figure 2 is situated between latitude 09°56′00″ south and longitude 33°56′00″ east with altitude of 478 meters above sea level. Karonga District is mostly rural, covering 3,355 km^2 and with population of 365,028 at the last census in 2018 (NSO 2019). The district's eastern border is Lake Malawi, which serves as an economic resource primarily for small-scale fisheries (Karonga District Council 2013). The study district is prone to cholera and natural disasters including earthquakes, strong winds and floods (Manda & Wanda 2017). Further, there are no municipal sewer systems in the district.

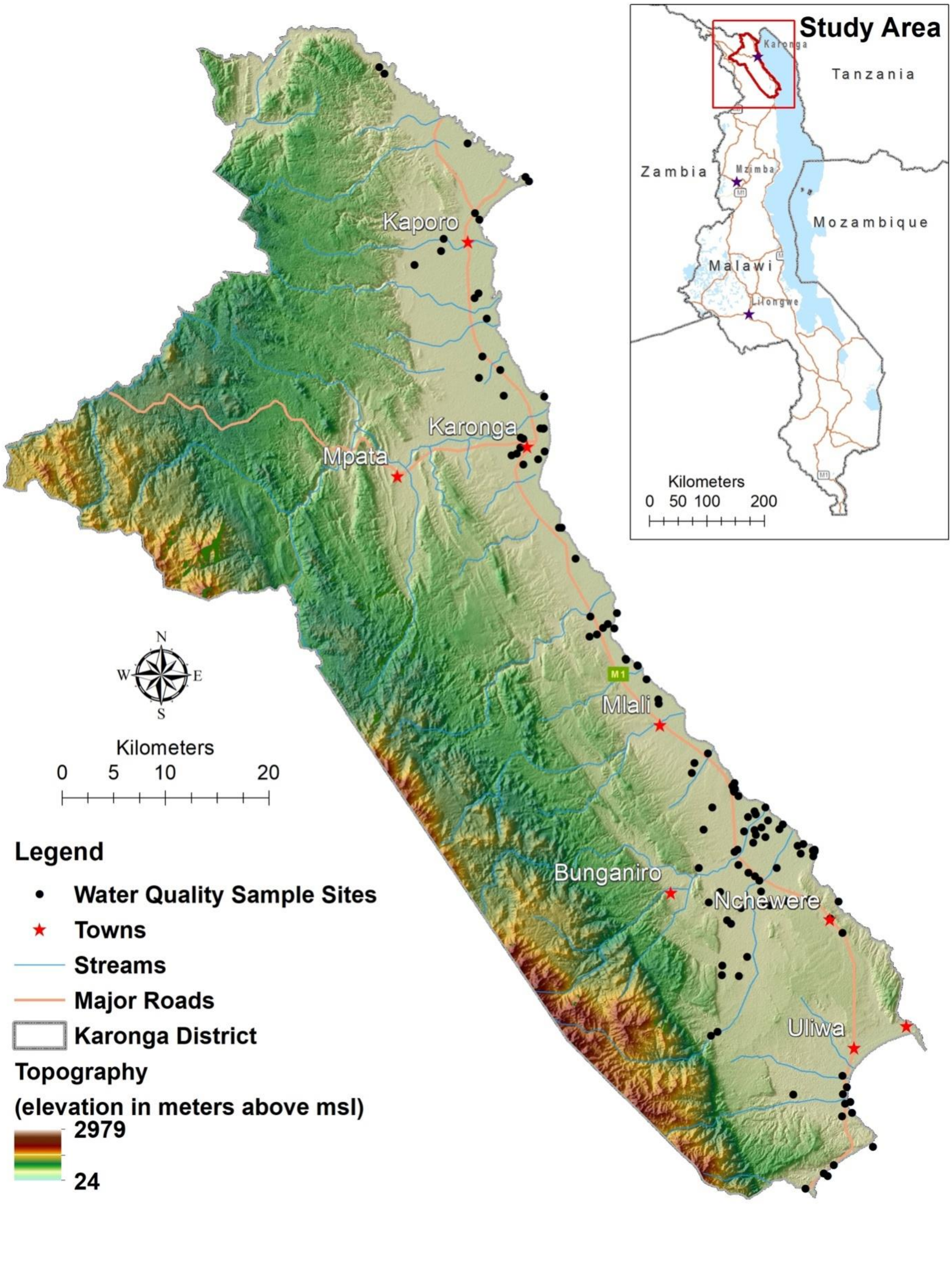

Figure 2: Study area with water quality sampling sites in Karonga District, Malawi

3.2 Research design

The study followed a case study design where a population of the 2017/18 cholera patients in Karonga District was studied with respect to their drinking source quality, used water treatment, risk perceptions, knowledge of cholera, and socio-economic characteristics. The data collection methods used were quantitative:

- water samples were collected and analysed for microbial and physico-chemical parameters
- a cholera patient survey was also administered to gather data on water treatment practices, risk perceptions, knowledge of cholera, and socio-economic characteristics.

3.3 Sampling framework and methods

The 2017/18 cholera cases were approximately distributed in Karonga District as follows: Senior Chief (SC) Mwirang'ombe (147); Traditional Authority (TA) Kyungu (103); TA Wasambo (78); TA Kilupula (15); and TA Mwakaboko (4) (Table 2). The study attempted to reach all the 343 unique cholera cases but only 236 cases were traced representing 69%.

Table 2: Number of sampled cases from each Traditional Authority.

Traditional Authority	Total reported cholera cases	Total traced in the study	Percentage sampled (%)
Kilupula	15	15	100
Kyungu	103	79	77
Mwakaboko	4	4	100
Mwirang'ombe	147	88	60
Wasambo	78	50	64
Total	**347***	**236**	**68**

[*]The total number of reported cases was 347, however 4 patients got re-admitted and recorded twice thereby making only 343 unique cases.

Data of suspected cholera cases, where patients had reported to a health centre for cholera treatment during the 2017/2018 outbreak in Karonga District were provided by the Malawi Government Ministry of Health. Water sampling sites were for all the primary water sources used by the cholera affected households which were traced. These included municipal taps provided by water board, boreholes, shallow wells, rivers and Lake Malawi.

3.4 Data collection

The field study was conducted in August 2018. A total team of thirteen people were involved in the data collection process including: the researcher (laboratory lead); four assistants; eight drivers (rotating in groups of two after one week). The research assistants were knowledgeable on data collection using tablets but they were trained to familiarise with the data collection tools. They were also trained on water sample collection and on-site sample analysis using potable meters for pH, temperature and turbidity. The field work started on 5th of August and was completed on 29th of August covering a total number of 25 days. This study analysed a total of 120 drinking water samples which were linked to 236 cholera patients (69% of patients could be tracked, n = 343). There were a number of reasons as to why some cases could not be traced. The main reasons included: The Health Surveillance Assistants (HSAs) and the villagers could not identify the names of the patients on the cholera line listing. In senior chief Mwirang'ombe, most of the patients could not be traced because they were fishermen who only go to the fishing camps during the fishing seasons. The other reason for un-traceability was the relocation of people to areas where no one could identify including the HSAs. This issue of relocation was noticed mainly at Karonga Town. Further, the HSAs or volunteers who were escorting the field teams could have a different list from the list which the team had collected from the district hospital. Complicated cases were also noted where patients did not want to be identified or traced so they could use fake names and villages.

3.4.1 Water sample collection and analysis

Water quality analysis included microbiological (thermotolerant coliform bacteria), and physico-chemical analyses (turbidity, pH, temperature, EC, TDS and salinity) which were sequentially replicated twice to obtain average results catering for variability among samples resulting from collection, processing and transportation (Figure 3).Standard water sampling procedures were followed as outlined in Malawi Standards for "borehole and shallow well water quality specification MS 733:2005" (Malawi Bureau of Standards 2005). Water sampling protocol for Mzuzu University Centre of Excellence in Water and Sanitation (procedure number 9, revision 0) was also followed.

Figure 3: Analysis of turbidity (left), TDS, EC and salinity (right) in the field laboratory

In 6 cases, the patient reported to be using more than one drinking water source. In these cases, samples from each source were collected and analysed, and the researcher conservatively chose the higher risk sample (based on higher thermotolerant coliforms and/or electrical conductivity) for inclusion to link to the patient. Additionally, for 116 patients, the patient was sharing his or her water source with another person from the study sample of cholera cases. In these cases, only one sample was collected but the single result was linked to each concerned patient. Hence, a total of 120 drinking water samples were analysed.

3.4.2 Microbiological analysis

Thermotolerant coliform bacteria was used as a proxy indicator of faecal contamination based on WHO recommendation on specifications for drinking water quality analysis (WHO, 2017). The water samples were collected into Whirl-Pak® bags containing sodium thiosulfate preservative (Nasco, FortAtkinson, Wisconsin, USA) to offset any existing residual chlorine. Analyses were performed within 6 hours following the sample collection, before the preservative stopped being effective. The Wagtech Potatest® Membrane Filtration Unit was used: 100ml duplicate samples incubated at 44ºC for 18 hours. One equipment blank was analysed daily for thermotolerant coliform field laboratory contamination using boiled and cooled water as recommended by MBS and WHO standards. Analysis of the water samples was done at a central location where the laboratory was set in the study area in Karonga to ensure samples were analysed within 6 hours after sample collection

3.4.3 Physico-chemical analysis

For pH, temperature, turbidity, EC, TDS and salinity analyses, samples were collected into Whirl-Pak® bags without sodium thiosulphate preservatives (Nasco, Fort Atkinson, Wisconsin, USA) in cases where the analyses were not done onsite.

Determination of pH and temperature

Determination of pH and water temperature was done using the Wagtech pocket pH sensor (Model 2571618, Palintest®, Kentucky, USA). A small volume (about 5 ml) of the sample was collected in the protective cap of the pH meter which is used as a sample container. Then the pH meter electrode was inserted to measure the pH and temperature of the water after calibrating using standard buffers of pH 7.00 and 4.00 at 25 ºC. The electrode was rinsed with distilled water before taking another measurement. This was done to avoid cross contamination.

Determination of turbidity

Jackson turbidity tubes from the Wagtech Potatest® kit (Palintest®, Kentucky, USA) were used for turbidity measurements directly in the field or in the field laboratory. The units of measurements were Jackson Turbidity Units (JTU). Water samples were added slowly into the tubes until the cross which is at the base of the tubes was not clearly visible. The readings were taken from the level of the sample against the reference scale on the tube. An estimate of the result was made if the level of the water was between two values on the scale.

Determination of EC, TDS and salinity

Determination of EC, TDS and salinity was done using the STARTER 3100C Bench Conductivity Meter in the field laboratory. About 50 ml of water sample was put in a glass beaker and electrode was inserted for measurement. This was done in duplicate. Measurements of EC, TDS and salinity were done from one sample before going to the next by switching using the mode button. Units of measurement used were µS/cm for EC, mg/l for TDS, and PSU for salinity.

3.5 Cholera patient survey and water point observation

The survey attempted to reach each of the 343 patients or a relative that lived in the same household. In the case of a deceased patient, a relative was sampled. In the case of children, an adult was interviewed on their behalf. In total, 236 out of 343 patients were located. For each patient, an interview was conducted in the local language of the area (Chitumbuka, Chichewa or Chinkhonde). Further, site observations were made, GPS coordinates of interview location and water source taken, and a sample from the main drinking water source (taps, boreholes, Lake Malawi, rivers and shallow wells) was collected. The interview was designed to assess patient's knowledge of cholera and their hygiene practices. This included questions on signs and symptoms, transmission pathways, methods for treatment (of cholera and water supply), methods of prevention and patient's perception of his or her own risk. On socio-economic status, a question of household asset ownership was included to assess household wealth level (Appendix C). The interviews were conducted by a member of the field team on an Android device using Open Data Kit (ODK) software (Free and Open Source software, University of Washington, Seattle, Washington, USA). The researcher also collected water point site observations using a checklist (Appendix C), referencing details such as the category of water source (improved, unimproved).

3.6 Data Analysis

All statistical analyses were done using Statistical Package for Social Science (SPSS) version 20 based on each specific objective (Table 3). GPS coordinate data collected from each water source were used to produce maps in ArcMap software version 10.6. Kruskal-Wallis One-way ANOVA; one sample T-test, Mann Whitney test and descriptive statistics (mean, standard deviation, and standard error) were used to analyse water quality data. Kruskal-Wallis One-way ANOVA was used because continuous water quality data was not normally distributed to quality for parametric statistics (ANOVA). One sample T-test (used to test significant difference in means of a continuous variable against a hypothesised value) was used to test significant differences in water quality data (microbiological and physico-chemical) against set guidelines by Malawi Bureau of Standards (MBS) and World Health Organisation (WHO). Mann Whitney test (a nonparametric test) was used as an alternative for parametric independent t-test to compare mean differences between two independent groups where dependent variables were ordinal or continuous e.g. patient's age. Duncan's multiple range test (a post hoc test for specific differences in means) was used to separate significantly different means. Chi-square test (a nonparametric test for association of two categorical variables) was used to analyse the association between water treatment, risk perceptions, cholera knowledge and wealth status at 95% confidence level. These tests were chosen based on the type of data and following guidelines on choice of statistical tests as described by Prel et al. (2010). The $p = 0.000$ means $p \ll 0.0005$ in the study as also reported by Noyez et al. (1998).

The patient interview data was coded by hand based on *a priori* framework (predetermined). Three scores were developed for each patient:

1) Safe water treatment practices. For safe water treatment practices, respondents were ranked as *'good'* if they reported practicing boiling, using chlorine or using a water filter; ranked as '*moderate*' for reporting that they let water settle or filtered it through a cloth; and '*poor*' for performing no treatment. Researchers did not independently verify reported household water treatment practices

2) Knowledge of cholera. For cholera knowledge, given that all respondents had been admitted for cholera or had a family member admitted, they likely had received information from the hospital regarding the symptoms of cholera and how to treat it. Respondents were ranked as having *'good',* '*moderate*,' or '*poor*' knowledge based on their reporting with one or more responses to five survey questions on prevention, transmission and treatment (Appendix C).

3) Risk perception. For the future cholera risk perception assessment, respondents were ranked as '*low*,' '*moderate*,' or '*high*' based on two survey questions: 'What level of risk do you think you have in getting cholera?' and 'How confident are you that your village/community/area can control the spread of cholera if there were another outbreak in the future?'

Table 3: Data analysis for each specific objective

Specific Objective	Independent variable(s)	Dependent variable(s)	Analysis method	Package of analysis
1. To determine microbiological (thermotolerant coliform bacteria) and physico-chemical quality (pH, temperature, turbidity, electrical conductivity, total dissolved solids and salinity) of water from main drinking water sources used by cholera affected households during the 2017 – 2018 cholera season in Karonga.	- TAs - Water source type	Thermotolerant coliform bacteria, pH, temperature, turbidity, EC, TDS and salinity levels	- Kruskal-Wallis One-way ANOVA - Descriptive statistics (mean, standard deviation, and standard error)	SPSS v. 20
2. To investigate household point-of-use water treatment practices for the 2017 – 2018 cholera affected households in Karonga.	- Household asset ownership - Water source type	- Household water treatment practice (categorical)	- Chi-square test - Cross-tabulation - Frequencies	SPSS v. 20
3. To assess the role of human demographics (risk perceptions, knowledge and socio-economic status) on cholera incidence during the 2017 – 2018 cholera season in Karonga.	- Household asset ownership - Water source type	- Knowledge of cholera - Risk perceptions	- Chi-square test - Cross-tabulation - Frequencies	SPSS v. 20

3.7 Research dissemination strategy

A full report (in this case thesis) was submitted to the Faculty of Environmental Science in fulfilment of the requirements of the award of Master's Degree in Water Resources Management and Development. To further disseminate to wider global audience, one peer reviewed journal article has been published in Water Supply Journal titled 'Drinking water quality and human dimensions of cholera patients to inform evidence-based prevention investment in Karonga District, Malawi' (https://iwaponline.com/ws/article/doi/10.2166/ws.2019.086/67810/Drinking-water-quality-and-human-dimensions-of). Results were also shared with the district stakeholders and other stakeholders, including UNICEF, through a presentation which was made at a dissemination seminar held on 27th November, 2018 at Mzuzu University. A second article titled "Household water treatment, an economic perspective: case of 2017/18 cholera patients in Karonga District, Malawi" was accepted on 11th July, 2019 for oral presentation in the 20th WaterNet/WARFSA[1]/GWPSA[2] Symposium held in Johannesburg, South Africa from 30th October to 1st November 2019.

[1]Water Research Fund for Southern Africa
[2] Global Water Partnership South Africa

CHAPTER 4: RESULTS

This chapter presents findings of the study following the order of study objectives: drinking water quality results (microbiological and physico-chemical), household point of use water treatment practices and human dimensions (risk perceptions, knowledge and socio-economic status).

4.1 Microbiological quality of drinking water

Table 3 summarises the microbiological quality results for the 120 drinking water samples which were analysed in the study compared to Malawi drinking water standard specification and international standards (WHO).

Table 4: Microbiological quality of 120 samples compared with Malawi and World Health Organization drinking water guidelines

Parameter	Thermotolerant coliform (cfu/100ml)
Minimum	0
Mean	35
Median	1
Maximum	>200 [c]
MBS[a] guideline	50
Percentage of samples that pass MBS guideline (%)	81
WHO[b] guideline	0
Percentage of samples that pass WHO guideline (%)	49

[a]MBS: Malawi Bureau of Standards (2005)
[b]WHO: World Health Organization (2017)
[c] Result was too numerous to count, upper detection limit of method is reported.

Based on thermotolerant coliforms, many patients had safe drinking water. The majority of the samples (81%, n = 120) met the Malawi Bureau of Standards (2005) drinking water criteria of 50 cfu/100 ml with p = 0.001 showing that there were significant differences between compliant (81%) and non-compliant (19%) samples to 50 cfu/100 ml. Almost half of the samples (49%, n = 120) met the more stringent WHO (2017) guideline of 0 cfu/100 m land there were also significant differences between compliant and non-compliant samples (p = 0.000). Figure 4 shows the mapped water quality results for the 120 analysed samples.

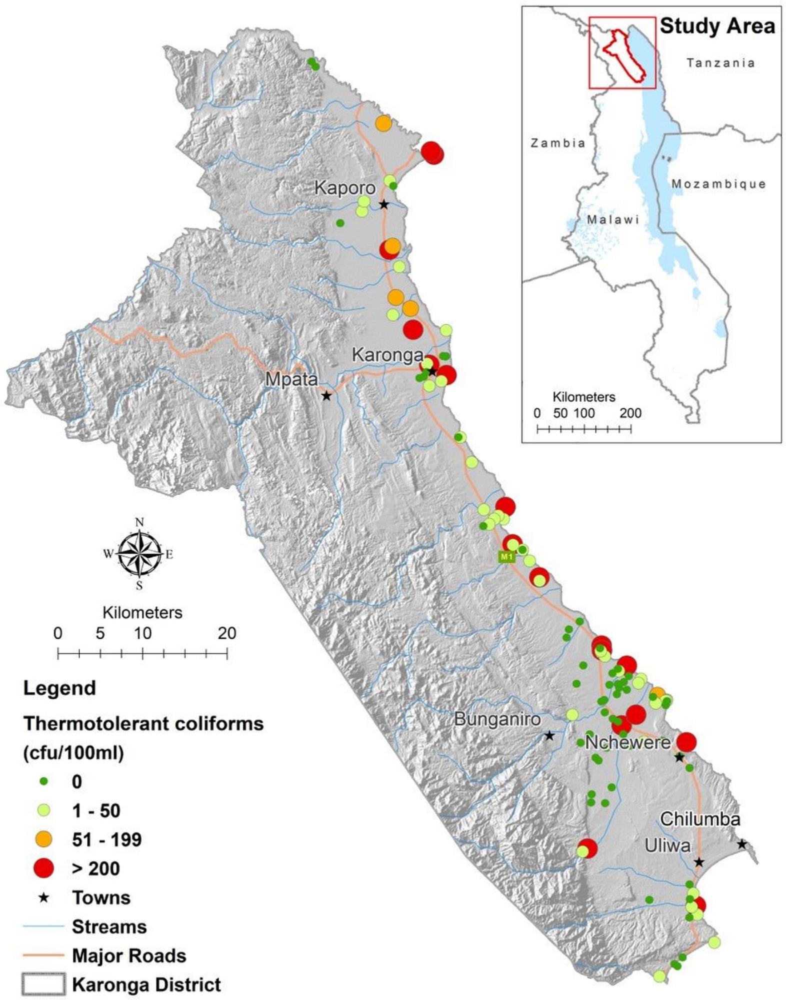

Figure 4: Thermotolerant coliforms in drinking water for cholera cases, Karonga District, Malawi (*n* = 120 water sources covering 236 cholera patients)

From the 120 samples, 22 geographic areas recorded the poorest microbiological quality level (>200 cfu/100 ml) and their distribution is mapped as shown in Figure 5. Though distances were not calculated, but the distribution of these 22 sites with poor water quality was close to the Lake with one outlier in TA Wasambo.

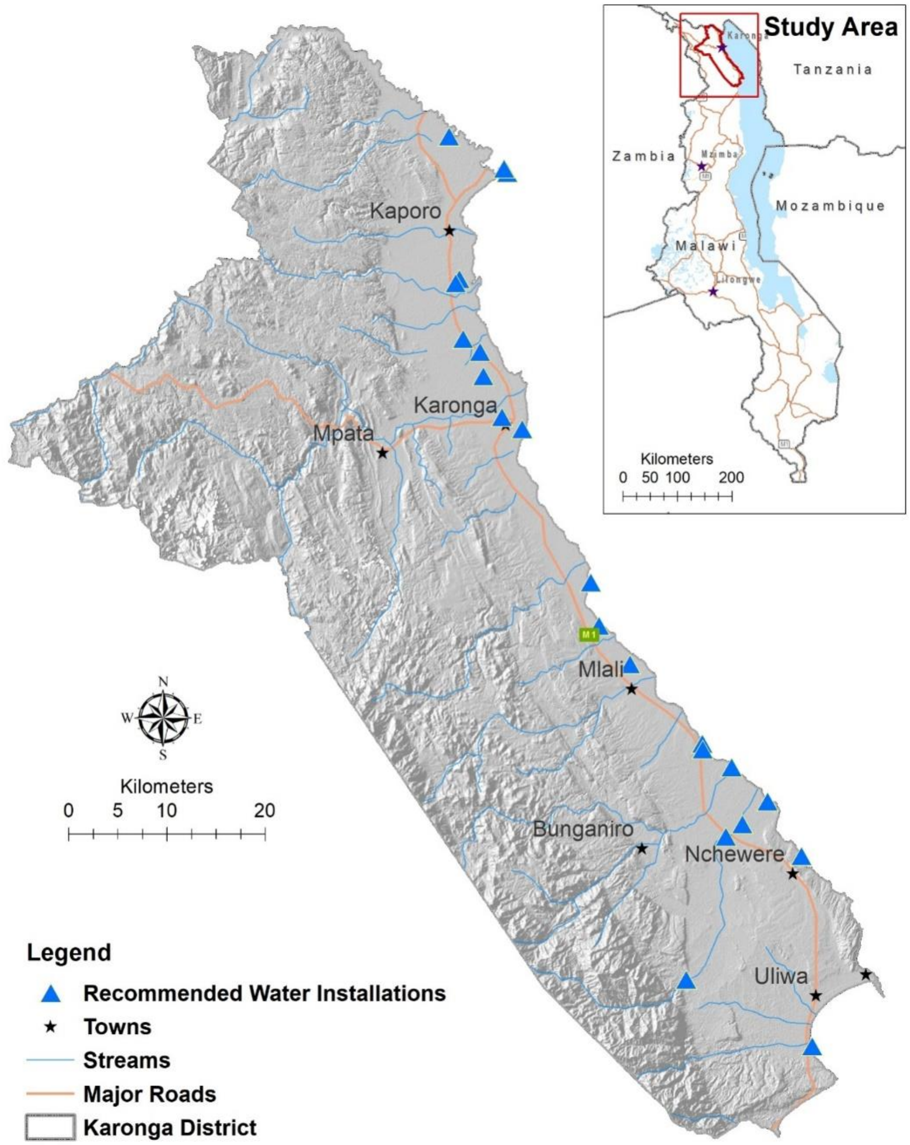

Figure 5: The 22 geographical sites with poor drinking water quality requiring water installations

Kruskal-Wallis One-way Analysis of Variance (ANOVA) results showed differences in mean thermotolerant coliforms across the 5 study Traditional Authorities in the District (p = 0.001). Samples from TA Kilupula recorded the highest thermotolerant coliform results but it was not statistically different from TA Kyungu, Mwirang'ombe, and Wasambo (p = 0.108) (Table 5).

Samples from TA Mwakaboko recorded the lowest thermotolerant coliform results (mean = 0 cfu/ml) but this was not statistically different from results obtained from TA Kyungu, Mwirang'ombe and Wasambo (p = 0.148). The lowest thermotolerant coliform results obtained in TA Mwakaboko coincided with the smallest number of cholera cases (4) recorded in the area. Mwirang'ombe recorded the highest number of cases (147) and its mean thermotolerant coliform results were also not significantly different from the highest mean obtained in TA Kilupula (Table 5).

Table 5: Microbiological quality results across Traditional Authorities

Traditional Authority (TA)	Parameter (Mean ± Std. Error)
	Thermotolerant coliform (cfu/100 ml)
Kilupula	68.32 ± 18.53^{a}
Kyungu	40.79 ± 8.79^{ab}
Mwakaboko	0.00 ± 0.00^{b}
Mwirang'ombe	28.50 ± 6.37^{ab}
Wasambo	23.08 ± 9.52^{ab}

$^{a\text{-}b}$Means separation superscripts from Duncan's Multiple Range Test showing that means with a common superscript in a column are not significantly different (p>0.05) at 95% confidence level where mean with 'a' is largest and 'b' is lowest.

Cholera patients were using both improved water sources (protected shallow wells, boreholes or piped water from a tap) and unimproved sources (Lake Malawi, surface or river water or unprotected shallow wells) (Figure 6).

(A) **(B)**

Figure 6: Cholera patient drinking water sources. (A) Improved, borehole as water source (B) Unimproved, Lake Malawi as water source

However, the improved water sources were not necessarily safe. Over half (54%, n = 236) of patients reported that they collected drinking water from an improved water source (protected shallow well, borehole or piped water). Patients drinking from unimproved sources (Lake Malawi, surface water or unprotected shallow wells), were more often drinking directly from Lake Malawi (61%, n = 109). Kruskal-Wallis tests indicated there were significant differences (p = 0.000) in thermotolerant coliforms level between the water sources (borehole, Lake Malawi, piped water, protected shallow well, surface or river water and unprotected shallow well) used by patients. River samples recorded the highest significant number of colonies followed by un-protected shallow well samples which were not significantly different from Lake Malawi samples (p = 0.135). Duncan's Multiple Range Test results further showed that thermotolerant coliform results for Lake Malawi samples were not significantly different from tap water results (p = 0.121) which were also not different from borehole and protected shallow well samples (p = 0.225). Table 6 presents water quality results across water source types. The 120 analysed water samples were from boreholes (52/120), Lake Malawi (29/120), piped tap water (8/120), protected shallow wells (10/120), rivers (7/120) and unprotected shallow wells (14/120). Of the 29 samples from Lake Malawi, 9 met the WHO guideline and 22 met the Malawi Bureau of Standards (2005) for thermotolerant coliforms.

Table 6: Microbiological quality of 120 samples for different water sources compared with Malawi and World Health Organization drinking water guidelines

Water Source (total: 120 samples)	Parameter (Mean ± Std. Error)
	Thermotolerant coliforms (cfu/100 ml)
Protected shallow well (10/120)	$3±2^{d}$
Un-protected shallow well (14/120)	$79±16^{b}$
River (7/120)	$140±26^{a}$
Lake Malawi (29/120)	$53±11^{bc}$
Tap water (8/120)	$26±17^{cd}$
Borehole (52/120)	$7±3^{d}$
MBS guideline	50
Percentage of samples that pass MBS guideline (%)	81
WHO guideline	0
Percentage of samples that pass WHO guideline (%)	49

[a-d]Mean separation superscripts from Duncan's Multiple Range Test showing that means with a common superscript in a column are not significantly different (p>0.05) at 95% confidence level where mean with 'a' is largest and 'd' is lowest.

Table 7 shows mean microbiological drinking water quality results across TAs and water source types. Results showed that the largest mean thermotolerant coliform level (200 cfu/100 ml) was recorded from river water samples from TA Kilupula. River water samples analysed in the study were only collected from TA Kilupula and TA Mwirang'ombe which also had relatively large mean thermotolerant coliform value (128.40 cfu/100 ml). Protected water sources (taps, borehole and protected shallow wells) recorded relatively lower mean thermotolerant coliform results in the range of 0 - 17 cfu/100 ml except tap water from TA Kyungu which recorded mean of 51 cfu/100 ml.

Table 7: Mean microbiological quality results across TAs and water source types

	Water source type					
	PSW	**UPSH**	**River**	**Tap**	**Borehole**	**LMW**
TA	**Parameter: Mean ± Std. Deviation**					
Kyungu	1.17±1.32	112.80±83.45	NA	50.75±92.14	0.58±1.86	57.58±84.71
Kilupula	0.88±1.12	136.25±68.45	200±0.00	3±1.41	0.00±0.00	NA
Mwakaboko	NA	NA	NA	0.00±0.00	0.00±0.00	NA
Mwirang'ombe	0.00±0.00	0.70±1.16	128.40±93.49	0.00±0.00	4.48±12.80	46.70±79.42
Wasambo	11.50±13.33	NA	NA	0.00±0.00	16.86±52.22	67.50±102.64

PSW: Protected Shallow Well UPSW: Unprotected Shallow Well LMW: Lake Malawi
NA: Not available as no samples were collected from that source in a particular TA

Table 8 presents microbiological quality of drinking water compared to patient age, gender and survival outcome. Mann-Whitney tests indicated median thermotolerant coliforms were not significantly different between patients who had died and those who survived cholera ($p = 0.29$) and median thermotolerant coliforms were not different between patient gender ($p = 0.18$). Linear regression analysis showed that there is no significant correlation between thermotolerant coliform detections and patient age ($p = 0.10$; regression coefficient of 0.011).

Table 8: Source microbiological quality of drinking water compared to gender, age, and survival outcome for patients during the 2017/2018 cholera outbreak, Karonga District, Malawi (*n* = 236)

	Discharged alive (*n* = 229)								**Cholera deaths (*n* = 7)**							
Thermotolerant coliform count (cfu/100 ml)		**Gender**		**Age (years)**						**Gender**		**Age (years)**				
	Total	M	F	<18	18-29	30-45	46-64	65+	Total	M	F	<18	18-29	30-45	46-64	65+
0	105	54	51	34	28	30	12	1	2		2	1			1	
1-50	87	52	35	34	22	18	9	4	3	3		1		2		
51-199	7	4	3	2	1	4										
200+	30	18	12	4	12	11	2	1	2	1	1					2

M = Male F = Female

There were no significant differences in terms of survival outcome (p = 0.71). This implies that there is no association between water source type and whether the patient died or survived cholera. As well, the Chi-square test showed no significant difference in terms of patient gender and whether they were drinking from improved or unimproved drinking water source (p = 0.50). A Mann-Whitney test indicated there was no significant difference in patient ages and whether they were drinking from improved or unimproved drinking water source (p = 0.36).

4.2 Physico-chemical quality of drinking water

Table 9 presents the physico-chemical water quality results for the 120 water samples compared with drinking water standards (local and international).

Table 9: Physico-chemical water quality of 120 samples compared with Malawi and World Health Organization drinking water guidelines

Parameter	**pH**	**Temperature (ºC)**	**Turbidity (JTU)***	**Electrical conductivity (µS/cm)**	**TDS (mg/l)**	**Salinity (PSU)**
Minimum	6.00	22.40	<5	18.80	9.40	0.02
Mean	7.68	26.60	18	320	159.09	0.16
Median	7.46	26.10	<5	202	100.90	0.10
Maximum	9.98	33.60	>500	1393	696.50	0.70
MBS [a] guideline	6.0 - 9.5	NA	25	3500	2000	NA
Percentage of samples that pass MBS guideline (%)	93	NA	89	100	100	NA
WHO[b] guideline	6.0 - 8.5	NA	1	750	1000	NA
Percentage of samples that pass WHO guideline (%)	78	NA	0	91	100	NA

[a] MBS: Malawi Bureau of Standards (2005), Borehole and shallow well water quality. MS 733
[b]WHO: World Health Organisation (2017), Guidelines for drinking water quality
NA: Not available
* Level of detection method was <5 JTU, higher than WHO standard

4.2.1 pH

The pH (6 - 9.98) of the 120 samples showed that majority of the samples (93%, $n = 120$) fit within the acceptable limits of Malawi Bureau of Standards criteria of 6.0 - 9.5. Further, a significant number of samples (78%, $n = 120$) were within WHO criteria of 6.0- 8.5. There were significant differences in mean pH results between complaint and non-compliant samples compared to MBS limits ($p = 0.000$) and WHO guideline ($p = 0.000$). There were significant variations in pH across TAs ($p = 0.000$) with TA Kyungu recording highest ones, followed by Mwirang'ombe, Mwakaboko and Wasambo (Table 10). There were significant differences in mean pH between different water sources used by the patients with tap water source recording the highest average pH (8.76) (Table 11). Lake water source recorded the second largest average pH (8.21) but it was not significantly different from river water samples ($p = 0.078$). There were no significant variations in pH for borehole and river water samples ($p = 0.119$). Samples from boreholes, protected and un-protected water sources were not significantly different in terms of pH ($p = 0.091$). Table 12 shows cross tabulation results for water source type, per TA by physico-chemical quality data. Tap water in TA Kyungu recorded the highest average pH (9.84) which was alkaline.

Table 10: Physico-chemical quality results across traditional authorities

	Parameter (Mean ± Std. Error)					
Traditional Authority	***pH***	***Temperature (ºC)***	***Turbidity (JTU)***	***Electrical conductivity (µS/cm)***	***Total dissolved solids (mg/l)***	***Salinity (PSU)***
Kilupula	6.84 ± 0.21^{c}	27.16 ± 0.32^{ab}	10.00 ± 1.61^{a}	71.00 ± 6.74^{b}	35.37 ± 3.38^{b}	0.04 ± 0.00^{b}
Kyungu	8.28 ± 0.14^{a}	26.99 ± 0.26^{ab}	20.50 ± 3.67^{a}	351.86 ± 35.85^{a}	175.92 ± 17.91^{a}	0.18 ± 0.02^{a}
Mwakaboko	7.48 ± 0.66^{b}	28.10 ± 0.52^{a}	5.50 ± 0.50^{a}	112.75 ± 19.35^{b}	55.25 ± 9.10^{b}	0.00 ± 0.00^{b}
Mwirang'ombe	7.62 ± 0.05^{b}	26.10 ± 0.14^{b}	21.78 ± 7.16^{a}	406.58 ± 31.20^{a}	201.26 ± 15.16^{a}	0.20 ± 0.02^{a}
Wasambo	7.19 ± 0.09^{bc}	26.72 ± 0.34^{ab}	8.20 ± 1.11^{a}	199.51 ± 18.99^{ab}	99.67 ± 9.48^{ab}	0.10 ± 0.01^{ab}
MBS guideline	6.0 - 9.5	NA	25	3500	2000	NA
WHO guideline	6 - 8.5	NA	1	750	1000	NA

$^{a-b}$ Mean separation superscripts from Duncan's Multiple Range Test showing that means with a common superscript in a column are not significantly different (p>0.05) at 95% confidence level where mean with 'a' is largest and 'b' is lowest.
MBS: Malawi Bureau of Standards (2005), Borehole and shallow well water quality specification. MS 733
WHO: World Health Organisation (2017), Guidelines for drinking water quality
JTU: Jackson Turbidity Units
NA: Not Available

Table 11: Physico-chemical quality results across water source types and comparison with drinking water standards

Water Source	Parameter (Mean ± Std. Error)					
	pH	***Temperature (ºC)***	***Turbidity (JTU)****	***Electrical conductivity (µS/cm)***	***Total dissolved solids (mg/l)***	***Salinity (PSU)***
Protected shallow well	7.02±0.20[d]	26.60±0.33[a]	11.50±3[b]	168.95±31.14[bc]	84.44±15.56[bc]	0.13±0.04[abc]
Un-protected shallow well	7.18±0.15[d]	26.83±0.23[a]	46.21±24[a]	282.77±58.39[ab]	130.52±25.16[abc]	0.14±0.03[abc]
River	7.80±0.22[bc]	26.37±0.63[a]	50.33±17[a]	96.81±28.54[c]	50.88±16.02[c]	0.05±0.01[c]
Lake Malawi	8.21±0.11[b]	26.33±0.26[a]	20.93±4[ab]	323.43±38.56[ab]	161.65±19.27[ab]	0.16±0.02[ab]
Tap water	8.76±0.30[a]	26.86±0.42[a]	15.13±6[b]	207.13±33.03[bc]	103.34±16.56[bc]	0.09±0.01[bc]
Borehole	7.44±0.07[cd]	26.69±0.19[a]	6.17±0[b]	400.20±29.94[a]	200.71±14.93[a]	0.20±0.01[a]
MBS guideline	6.0 - 9.5	NA	25	3500	2000	NA
Percentage of samples that pass MBS guideline (%)	93	NA	89	100	100	NA
WHO guideline	6.0 - 8.5	NA	1	750	1000	NA
Percentage of samples that pass WHO guideline (%)	78	NA	*0	91	100	NA

[a-d] Mean separation superscripts from Duncan's Multiple Range Test showing that means with a common superscript in a column are not significantly different (*p*>0.05) at 95% confidence level where mean with 'a' is largest and 'd' is lowest.

[*] Level of detection method was <5 JTU, higher than WHO standard

[**] JTU: Jackson turbidity units, level of detection <5. NTU = Nephelometric turbidity units. The two units are roughly equivalent (WHO Fact Sheet 2.33 -Turbidity measurement; http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_33.pdf)

NA: Not Available

MBS: Malawi Bureau of Standards (2005), Borehole and shallow well water quality specification. MS 733

WHO: World Health Organisation (2017), Guidelines for drinking water quality

Table 12: Cross tabulation of water source type and Traditional Authorities (TAs) by physico-chemical quality parameters

Water Source	Traditional Authority	Parameter (mean ± standard error)					
		pH	Temperature (°C)	Turbidity (JTU)	Electrical conductivity (µS/cm)	Total dissolved solids (mg/l)	Salinity (PSU)
Protected shallow well	Kilupula	6.39±.15	26.95±.44	5±0	52.96±11.76	26.48±5.88	0.03±0.00
	Kyungu	7.83±.49	27.68±0.56	20±9	307.48±42.81	153.68±21.36	0.29±0.12
	Mwirang'ombe	7.20±.00	25.00±0.00	5±0	349.50±2.50	174.60±1.10	0.17±0.00
	Wasambo	6.98±.10	25.08±0.15	15±6	102.83±5.60	51.40±2.81	0.06±0.00
Un-protected shallow well	Kilupula	6.74±.23	26.69±0.33	13±3	79.46±10.39	39.44±5.33	0.05±0.00
	Kyungu	7.04±.28	27.35±0.50	15±6	221.11±45.70	110.54±22.82	0.11±0.02
	Mwirang'ombe	7.68±.15	26.42±0.29	104±66	507.07±129.59	223.37±55.14	0.25±0.06
River	Kilupula	9.43±0.15	28.50±0.70	25±0	70.45±0.25	35.20±0.10	0.04±0.00
	Mwirang'ombe	7.48±0.04	25.94±0.67	55±20	102.08±34.29	54.01±19.23	0.06±0.02
	Kyungu	8.70±0.20	26.81±0.57	37±9	330.65±75.34	165.29±37.67	0.16±0.04
	Mwirang'ombe	7.86±0.10	25.83±0.08	11±3	340.65±47.91	170.24±23.93	0.17±0.02
	Wasambo	8.05±0.25	26.90±1.20	5±0	208.45±37.65	104.12±18.83	0.10±0.02
Tap water (Water board)	Kilupula	7.20±0.10	30.15±0.65	10±0	65.50±0.10	32.75±0.05	0.04±0.00
	Kyungu	9.84±0.03	25.91±0.18	24±12	150.14±1.27	75.06±0.63	0.08±0.00
	Mwakaboko	8.62±0.04	28.75±0.85	6±1	146.00±6.00	71.00±1.00	0.00±0.00
	Mwirang'ombe	7.50±0.00	25.65±0.15	5±0	447.50±1.50	224.00±1.00	0.22±0.00
	Wasambo	7.40±0.01	26.70±0.00	5±0	397.50±1.50	198.75±0.85	0.19±0.00
Borehole	Kilupula	6.15±0.05	25.55±0.05	5±0	115.40±0.30	57.45±0.05	0.06±0.00
	Kyungu	7.97±0.17	27.21±0.44	5±0	505.87±61.77	252.96±30.86	0.25±0.03
	Mwakaboko	6.35±0.15	27.45±0.25	5±0	79.50±0.50	39.50±0.50	0.00±0.00
	Mwirang'ombe	7.52±0.05	26.31±0.24	6±0	490.97±46.63	246.87±23.15	0.24±0.02
	Wasambo	7.02±0.08	26.92±0.40	8±1	197.26±23.10	98.54±11.52	0.10±0.01

4.2.2 Water Temperature

Water temperature affects portability of water and concentrations of organic and chemical contaminants in drinking water (WHO 2017). Microbial growth in water is enhanced by high water temperature. Temperature results ranged from 22.40ºC to 33.60ºC. There are no established guideline ranges for water temperature by MBS and WHO standards. There were significant differences in water temperature across TAs (p = 0.003). TA Mwakaboko recorded the highest mean water temperature (28.10 ºC) which was significantly different from lowest mean water temperature (26.10 ºC) obtained from TA Mwirang'ombe. TA Mwirang'ombe recorded the largest number of cholera cases. There were no significant differences (p = 0.785) in mean water temperatures results across water source types.

4.2.3 Turbidity

Turbidity levels of the water samples ranged from <5 to >500JTU. The majority of the samples (89%, n = 120) pass the MBS standard of 25 JTU. The detection limit used in the study equipment was 5 JTU, higher than the WHO standard of 1 JTU. There were significant differences in mean turbidity results between complaint and non-compliant samples compared to MBS limit of 25 NTU (p = 0.028) and WHO guideline of 1 NTU (p = 0.000). There were no significant variations in turbidity levels across traditional authorities. Kruskal-Wallis one-way ANOVA results showed that there were significant differences in turbidity between the water sources used by the patients (p = 0.000) with river and unprotected shallow well water recording the highest levels.

4.2.4 Electrical Conductivity

Electrical conductivity (EC) results (18.8-1393 µS/cm) showed that all the samples (100%, n = 120) passed the national Malawi Bureau of Standards (2005) criteria of 3500 µS/cm and majority (91%, n = 120) were within the WHO criteria of 750 µS/cm. There were significant differences in mean EC results between complaint and non-compliant samples compared to MBS criteria (p = 0.000) and WHO guideline (p = 0.000). Kruskal-Wallis test results showed significant variations in EC results between traditional authorities with TA Mwirang'ombe and Kyungu recording significantly highest from TA Mwakaboko and Kilupula. EC levels for TA Wasambo was not significantly different from Mwirang'ombe, Kyungu, Mwakaboko and Kilupula. Significant differences in EC results between the water sources used by the patients (p = 0.000) were also observed with borehole water recording the highest.

4.2.5 Total Dissolved Solids

TDS parameter comprises inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water (WHO, 2017). Results ranged from 9.40 to 696.5 mg/l and showed that all the samples (100%, n = 120) were within both MBS and WHO limits of 2000mg/l and 1000mg/l, respectively. There were significant differences in mean TDS results between complaint and non-compliant samples compared to MBS limit (p = 0.000) and WHO guideline (p = 0.000). Significant variations in TDS across traditional authorities were observed with the same trend as for EC: TA Mwirang'ombe and Kyungu recorded the highest rates. There were significant differences in total dissolved solids results between the water sources used by the patients (p = 0.000) with borehole water recording the highest ones.

4.2.6 Salinity

Salinity results ranged from 0.02 to 0.70 PSU. There are no established guideline values by both MBS and WHO standards. Significant variations were observed in salinity values between TAs with the same trend as for EC and TDS: TA Mwirang'ombe and Kyungu recorded the highest ones. There were significant differences in salinity results between the water sources used by the patients (p = 0.000): boreholes recorded the highest values though not significantly different from protected and unprotected shallow wells and Lake Malawi water.

4.3 Household point of use water treatment

In terms of Household Water Treatment (HWT), the majority (70%, n = 236) of cholera affected households practiced HWT. Out of the households which reported practicing water treatment, 34% (55/164) commented they only treated when resources were available, often citing their dependence on the government health team for the supply. The reported water treatment mainly included use of chlorine solutions, boiling the water and use of water filter.

The study compared household assets owned (cell phone, radio, bicycle, television and car) in relation to water treatment at household level. As reference, the price of a chlorine product sachet was MK300 (USD$0.42, as of 25th May, 2019) while the lowest price for a cell phone was MK7, 500 (USD $10.38); for a radio: MK12, 000 (USD$16.61); for a bike: MK60, 000 (USD $83.04); and for a television: MK50, 000 (USD$69.2). The Chi-square test results revealed that there was a statistical difference (p = 0.046) between the number of assets owned by a household and whether or not they practiced HWT. The number of households which did not practice HWT decreased as the number of possessions owned by households increased (Table 13).

Table 13: Comparison of assets owned versus water treatment at household level

Number of assets owned	Practice HWT	Do not treat water	Total
0	35 (57%)	26 (43%)	61
1	65 (75%)	22 (25%)	87
2	38 (67%)	19 (33%)	57
3	19 (79%)	5 (21%)	24
4	7 (100%)	0 (0%)	7
Total	**164**	**72**	**236**

HWT: Household Water Treatment

There was no significant association between risk perception (p = 0.372) and knowledge of cholera (p = 0.176) with regard to water treatment. A comparison of microbiological quality results with household water treatment practice was also done. A significant number of respondents (66%, n = 32) who had poor microbiological quality of drinking water (200+ cfu/100 ml) reported treating water at household level (boiling or using chlorine products) (Table 14).

Table 14: Microbiological water quality compared to safe water treatment for patients during the 2017/2018 cholera outbreak, Karonga District, Malawi (*n* = 236)

Household safe water treatment	Total	Thermotolerant coliform count (cfu/100 ml)			
		0	**1-50**	**51-199**	**200+**
Good practices	160	64	71	3	22
Moderate awareness	3	1	1	1	
Poor understanding	73	42	18	3	10
Total	236	107	90	7	32

The study also compared households with access to protected and unprotected water sources in terms of household point-of-use water treatment. Above half of the respondents (59%, *n* = 236) were using protected water sources while moderate number of respondents (41%, *n* = 236) had unprotected water sources. Table 15 shows the number of households and people served by different water sources in the study area.

Table 15: Average number of households and people served by different water sources in the study

Water source type	Average number of households served	Average number of people served
Borehole	96	388
Shallow well	93	389
Kiosk/tap	94	409
Surface water	103	405

Table 16 shows results for water source versus HWT: more than half of the households (52%, *n* = 164) who reported practicing HWT were using borehole water. Many households (71%, *n* = 139) who reported using protected water source, practiced HWT and a significant number of households (68%, *n* = 97) which were using unprotected water source practiced HWT. A t-test for type of water source and practice of household water treatment revealed there was no significant difference ($p = 0.688$) in terms of water treatment practice between households which were using a protected water source and households which were using unprotected water source.

Table 16: Cholera patient's water source and water treatment

		Water source type						
		Protected water Source			Unprotected water Source			Total
		Borehole	Water kiosk/tap	Protected shallow well	Unprotected shallow well	River	Lake Malawi	(*n* = 236)
HWT	**Yes**	85 (52%)	4 (2%)	9 (5%)	10 (6%)	8 (5%)	48 (29%)	164
	No	28 (39%)	3 (4%)	11 (15%)	6 (8%)	5 (7%)	19 (26%)	72
Total		113	7	20	16	13	67	236

4.4 Risk Perceptions, Knowledge and Socio-economic Status

4.4.1 Household risk perceptions regarding cholera

With regard to risk perception of getting cholera in future, relatively many respondents (27%, *n* = 236) felt medium risk followed by no risk (24%), low risk (22%) and high risk (22%). Very few respondents (6%, *n* = 236) reported that they do not know their future level of risk of contracting cholera (Figure 7).

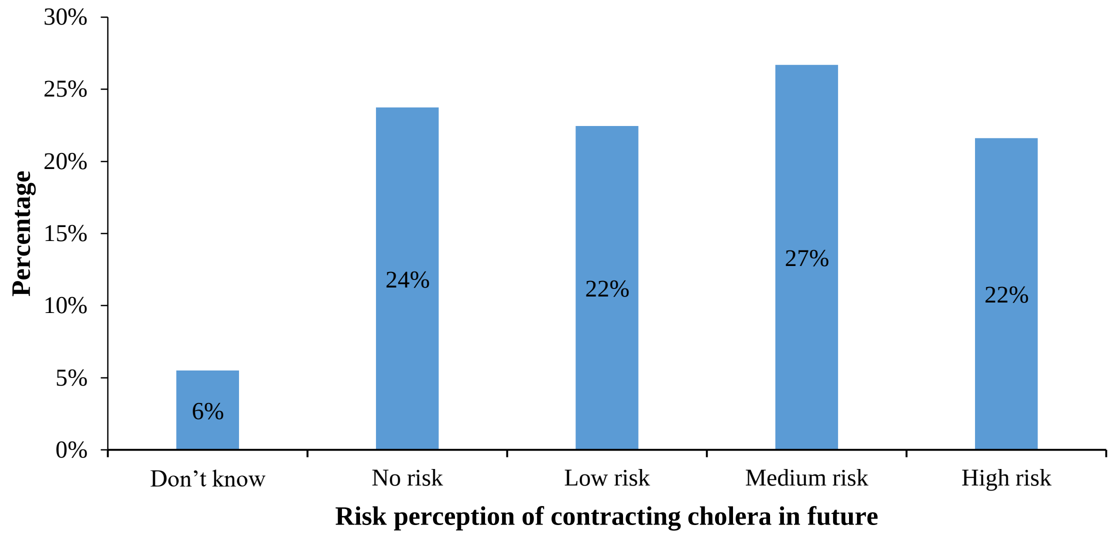

Figure 7: Respondent's future level of risk to contract cholera

Overall, about half of the respondents (41%, *n* = 236) were not very confident that they could control the spread of cholera in an event of another outbreak in future. Few respondents (29%, *n* = 236) were somewhat confident and others extremely confident (26%). Very few respondents (4%, *n* = 236) reported that they did not know whether they could control spread of cholera in future or not. Majority of respondents (86%, *n* = 51) who felt being at high risk of contracting cholera in future were also not very confident of controlling cholera spread (Table 17).

Table 17: Future risk perception of contracting cholera and level of confidence in controlling cholera spread

Level of confidence to control cholera in future	Future risk level of contracting cholera					
	Don't know	**No risk**	**Low risk**	**Medium risk**	**High risk**	**Total**
Don't know	3	1	0	3	2	9
Extremely confident	0	36	18	8	0	62
Somewhat confident	1	13	21	29	5	69
Not very confident	9	6	14	23	44	96
Total	13	56	53	63	51	236

Comparison of microbiological quality with risk perception showed that from the 32 people who had water source thermotolerant coliform levels of 200+ cfu/100 ml, 12 reported feeling that there was a low risk or zero risk to themselves of contracting cholera in the future and that their community was extremely well prepared to respond to another outbreak (Table 18).

Table 18: Microbiological water quality compared to future risk perception for patients during the 2017/2018 cholera outbreak, Karonga District, Malawi (*n* = 236)

Future risk perception	Total	Thermotolerant coliform count (cfu/100 ml)			
		0	**1-50**	**51-199**	**200+**

Future risk perception	Total	Thermotolerant coliform count (cfu/100 ml)			
		0	**1-50**	**51-199**	**200+**
Low likelihood	96	46	36	2	12
Moderate likelihood	82	35	34	3	10
High likelihood	58	26	20	2	10
Total	236	107	90	7	32

4.4.2 Knowledge on cause and transmission of cholera

Overall, respondents had a good awareness of cholera, with majority of them (67%, n = 236) identifying 'Consuming contaminated food and water' as a way of contracting cholera. However, very few respondents (11%, n = 236) indicated wind or bad air as a cause of cholera. Many respondents (87%, n = 236) were aware of one or more practices to prevent cholera, including use of a pit latrine, treating stored household drinking water, washing hands with soap and food safety. Very few respondents (2%, n = 236) thought that there is no treatment for cholera once a person gets sick. Although each patient in the study had reported to a government health centre for treatment, majority (90%, n = 236) indicated that this was an immediate step when signs and symptoms of cholera were present. No respondent indicated seeking traditional healers or traditional medicine.

Table 19 presents findings for comparison of knowledge of cholera and microbiological quality of drinking water. Of the 32 households who had poor water source quality (>200 cfu/100 ml), majority (75%) had good knowledge of cholera.

Table 19: Microbiological water quality compared to knowledge of cholera for patients during the 2017/2018 cholera outbreak, Karonga District, Malawi (n = 236)

Cholera knowledge	Total	Thermotolerant coliform count (cfu/100 ml)			
		0	**1-50**	**51-199**	**200+**
Good	180	92	61	3	24
Moderate awareness	52	12	28	4	8
Poor	4	3	1	0	0
Total	236	107	90	7	32

4.4.3 Household Socio-economic Status

Household assets were grouped from 0-4, where households with 0 assets were ranked as 'poorest', with 1 to 2 assets ranked as 'poor' and with 3 to 4 ranked as 'rich'. The cumulative percentage on ownership of the five assets from multiple responses used in the study showed that 61% had access to a cell phone (144/236), 27% had a radio (63/236), 31% had a bicycle (73/236), 5% had a television (12/236), 0.4% had a car (1/236), and 25% (60/236) had none of these 5 possessions.

Comparison of household wealth status and water source microbiological quality showed that cholera affected households who had poorest water source quality owned 0 – 2 assets (Table 20).

Table 20: Microbiological water quality compared to wealth status for patients during the 2017/2018 cholera outbreak, Karonga District, Malawi (*n* = 236)

	Thermotolerant coliform count (cfu/100 ml)				
Number of assets owned	**Total**	**0**	**1-50**	**51-199**	**200+**
0	61	28	23	1	9
1	87	34	38	4	11
2	57	31	16	0	10
3	24	11	9	2	1
4	7	3	4	0	0
Total	236	107	90	7	32

Table 21 shows results for cholera patient's household assets ownership and water source type accessed by the household. Pearson chi-square results showed that there was no significant association between the number of assets owned by a household and the type of water source being used (p = 0.315). About half of respondents (48%, n = 236) in the study were using borehole water and a few (28%, n = 236) were using Lake water. No household owning 4 assets and above were using Lake Malawi, rivers and unprotected shallow wells.

Table 21: Household assets by type of water source

Number of assets owned	Water source						Total
	Borehole	Water kiosk/tap	Protected shallow well	Unprotected shallow well	River	Lake Malawi	
0	25	3	5	4	4	20	61
1	42	3	6	5	3	28	87
2	28	0	4	6	6	13	57
3	14	0	3	1	0	6	24
4	4	1	2	0	0	0	7
Total	113	7	20	16	13	67	236

CHAPTER 5: DISCUSSION

This chapter presents interpretation of the results found in the current study providing explanations and links to literature and research hypotheses. The chapter is divided into subsections based on study specific objectives (microbiological and physico-chemical quality, household point-of-use water treatment, and human dimensions).

5.1 Microbiological quality of drinking water

There is limited data on drinking water quality for the past 10 years from Karonga District (Manda & Wanda 2017; Holm et al. 2018). Beyond the link to cholera patients, this investigation is one of the largest studies on drinking water quality conducted within the district. Manda and Wanda (2017) found that a considerable number of sources (56%, n = 27) were above the WHO guideline for *Escherichia coli* (E. coli) of 0 cfu/100 ml in drinking water, which is similar to the findings of this study where 51% were above the WHO guideline for drinking water. The results show that cholera patients in the current study were drinking better water in terms of microbiological quality compared to results from other studies in the district with a relatively few (19%, n = 120) who were drinking water of poor quality. This suggests that the patients with good water quality may have been exposed to other risk factors like consumption of contaminated food. Results showed that unprotected shallow wells recorded second largest mean thermotolerant coliforms in TA Kyungu and Kilupula. This is consistent with findings by Kamanula, Zambasa and Masamba (2014) in the southern region of Malawi where boreholes and shallow wells had high *E.coli*counts.

Nationally, access to drinking water estimates for rural areas of Malawi with at least basic coverage are at 63% (WHO & UNICEF 2017). In comparison, more than half (54%, n = 236) of cholera patients in this study were using an improved water source (protected shallow well, borehole or tap water) that would meet the criteria of basic coverage.

The majority of individuals (84%, n = 236) who contracted cholera had access to good quality water. It is evident therefore that human dimensions, including geographic, economic, and cultural factors, are likely the dominant contributors in cholera transmission in the region. Behaviour practices and other transmission pathways, such as eating contaminated food, may have been more significant in the spread of cholera in Karonga than water source quality or the practice of HWT. This is in line with Shaheed et al. (2014) report that in Cambodia microbiological quality of improved water sources was not maintained at the point of consumption due to mixing water sources at the household level, unsafe storage and handling practices, and inadequately treated water.

Generally, few of the cholera patients (28%, n = 236) were drinking from Lake Malawi. Shapiro et al. (1999) notes that Lake water is convenient drinking source among fishing communities, and encouraging alternative drinking water sources may not be practical. Males represent 99% of fishers, based on the last survey of Lake Malawi in 2015 (Government of Malawi 2017). Yet, it was not only men who were getting cholera and no differences in drinking water quality either drinking from improved or unimproved drinking water source were identified by gender in the current study. While women dominate domestic household water decisions, they may also have had better access to behaviour change communication interventions than men who spend long hours on a boat. There could be a role for manually drilled boreholes on the shoreline of Lake Malawi to provide improved water sources to rural communities. A new water source by manual drilling with an Afridev pump in the study area would cost M1,456,000 (USD$2,020), while a mechanically drilled well with an Afridev pump would cost MK3,400,800 (USD$4,720) to MK3,660,500 (USD$5,080) (personal communication with Isaac Mkandawire on 24 September 2018 and T&T Investment on 25 September 2018, Mzuzu, Malawi). Using climatic forecasts, Moore et al. (2017) predict that Malawi will have even more cholera incidences due to El Niño events, indicating that greater public health preparations are needed for a disease that will continue to be a challenge for local communities as well as the government. Msyamboza et al. (2014) note the importance of social and cultural norms related to cholera in health promotion, especially witchcraft and religion, among fishing communities. A study in rural Kenya by Shapiro et al. (1999) found a clear link between drinking water from Lake Victoria and cholera risk factor. Similarly, recent work by Tyner et al. (2018) in the Central region of Malawi found consistently high *E. coli* distribution in Lake Malawi shoreline water (90% samples were above WHO standards). In contrast, results of the current study on thermotolerant coliforms distribution in Northern region shoreline water were generally lower (69% of shoreline samples were above WHO standards). These studies highlight the need that communities on shores of African Great Lakes require culturally contextualized strategies for behaviour change interventions concerning drinking water uses. Although results from this study found no clear relationship between drinking water source type and incidence of or mortality from cholera, *Vibrio cholera* can survive in some aquatic environments for months to years (Momba & Azab El-Liethy 2017). The occurrence of *V. cholera* as a natural inhabitant of the Lake Malawi aquatic environment needs further study as well as ecological factors that may influence its occurrence, persistence and survival.

5.2 Physico-chemical quality of drinking water

Generally, the physico-chemical quality results in the current study showed that cholera patients were drinking better water according to MBS and WHO standards which is consistent with other studies in the district (Manda & Wanda 2017; Wanda et al. 2013; Mapoma et al. 2016; Mapoma et al. 2017). Further, Chimphamba and Phiri (2014) found that few boreholes (31.5%, n = 5,324) in Malawi recorded chemical concentrations (including pH) above WHO guideline for safe drinking water.

Study results for pH (6 - 9.98) were consistent with findings by other authors in the district (Wanda et al. 2013; Mapoma et al. 2016; Manda & Wanda 2017; Mapoma et al. 2017). Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection (WHO 2017). For effective disinfection with chlorine, the pH should preferably be less than 8; however, lower-pH water (less than pH 7) is more likely to be corrosive (WHO 2017). Evidence shows that cholera bacteria is endemic to aquatic environments and that pH of about 8.0 (Huq et al. 2005) and warm water temperatures (19 – 28 ºC) (Louis et al. 2003) are associated with its increased abundance.

Although most particles that contribute to turbidity have no health significance (even though they may indicate the presence of hazardous chemical and microbial contaminants), many consumers associate turbidity with safety and consider turbid water as being unsafe (WHO 2017; Khonje et al. 2012). Khonje et al. (2012) note that turbid water could be conducive for cholera bacteria growth. The WHO notes that consumers' loss of confidence in a drinking-water supply may lead to people drinking less water than required or use of alternatives with lower turbidity which may not be safe for consumption (WHO 2017). Significant high turbidity levels for river water observed in the current study (average of 50 JTU) is consistent with findings by Wanda, Gulula & Kushe (2014) who found turbidity levels in the range of 130 to 225 NTU in Lunyangwa river catchment and Gulliver dam. This was associated with anthropogenic activities which leads to increased levels of silt loads. Wanda et al. (2014) further noted that high turbidity levels led to increase in the amount of coagulant dose used to treat water where raw water of turbidity level of greater than 200 NTU used a coagulant dose of about 7.5 mg/l, which is higher than a 0.5mg/l dose use for less turbid water. DuBois et al. (2010) found that having turbid water as a source was a significant triggering factor for initial use of household-water treatment products.

Study results showed that TDS was within drinking water standards (<2000mg/l) and this was consistent with findings by other authors in Karonga District (Wanda et al. 2013; Mapoma et al. 2016; Manda & Wanda 2017; Mapoma et al. 2017). Water is conducive for drinking at TDS levels below 600 ppm and not good for consumption above 1000 ppm (WHO 2017). Consumer preference of the drinking water is also affected if water has high levels of TDS.

EC, TDS and salinity results revealed that TAs Mwirang'ombe and Kyungu recorded the highest compared to the other TAs (Table 9 and 11). This is consistent with reports from respondents in Mwirang'ombe who reported that the groundwater sources are salty and they opt to drink the fresh water from Lake Malawi. Salty water may have led people to seek other sources of fresh water at times and could also explain the highest number of cholera cases in TA Mwirang'ombe (147 cases of the 343 cases) and significantly high EC, TDS and salinity. This finding is consistent with results of Abedin, Habiba and Shaw (2014), where salinity was found to be the primary reason for lack of safe drinking water compared to arsenic and drought hazards in coastal Bangladesh. There is evidence that abundance of cholera bacteria is correlated with salinity levels in the range of 2 – 14 ppm (Louis et al. 2003). TA Mwirang'ombe has only one government health centre, Nyungwe Facility that provides outpatient, maternal and child health, HIV Testing and Counselling and Anti-Retroviral Therapy services. The TA has also one additional private clinic providing only outpatient and immunization services (with no maternity services). Other TAs tend to have more services. The Nyungwe facility is also entrusted with the oversight of 11 village clinics placed in hard to reach areas of the District, more than any other facility in the District (Karonga District Council 2013). TA Mwirang'ombe received the cholera vaccine during the 2017/2018 cholera outbreak through a single centre. This compares to TA Wasambo which distributed the vaccines through five locations, and TA Kyungu which distributed the vaccines through four locations. Thus, the high rate of cholera in TA Mwirang'ombe could be attributed to a combination of lack of safe water due to saline borehole water and lower ease of access to health services. Most of the study communities would be considered small, contained, communities with residents living within walking distance of the water source, similar to the conditions of John Snow's original research into cholera outbreaks in Soho, London (Snow 1855).

5.3 Household point-of-use water treatment

Results on water treatment show that a greater percentage (70%, *n* = 236) of cholera affected households practiced HWT. This is consistent with findings by Mkwate et al. (2017) who reported a majority of households (>95%, *n* = 204) in Balaka District practiced rural household water treatment. The greater percentage however, could be due to interventions which took place prior to the study in the areas and during which some organisations and government distributed chlorine products to the affected households. Higher water insecurity and vulnerability to cholera could also have led to the greater percentage of HWT practice (Shrestha et al. 2018; Kumwenda et al. 2014).

The association between number of household assets owned and HWT found in this study is consistent with findings by other authors (Manda & Wanda 2017; DuBois et al. 2010; Freeman et al. 2009). Manda and Wanda (2017) found a significant relationship between access to safe water and household monthly income in Karonga District: households with monthly income greater than MK 29,999 were more likely to use safe water. According to Freeman et al. (2009), wealthiest persons are more likely to chlorinate water. DuBois et al. (2010) in their study in western Kenya was able to link consistent usage of water treatment accessories with use of less costly and more accessible chlorine products. Additionally, they note that to increase usage of household-level water treatment there is need for treatment products to be consistently available at prices which at risk-populations can afford. This relates to economic empowerment of households with less asset portfolios. This finding may point to an important fact that those with more assets could afford HWT which may be difficult to those with fewer assets as the price of chlorination products may influence the uptake of water treatment practice at household level. This finding complements the conclusion by Clasen (2015), who suggested that the effectiveness of HWT can be optimized by ensuring that the products are accessible to an exposed population.

In terms of type of water source and HWT, the study has shown that most households (71%, n = 139) using a protected water source practice HWT, compared to those with an unprotected water source though the difference was not significant (p = 0.688).Use of unprotected water sources with turbid water is correlated with the practice of HWT as reports have shown that there is an association between households using turbid water sources and water treatment at household level (DuBois et al. 2010; Crump et al. 2005). It has been reported that it is necessary that communities be made aware of the right doses of chlorine solutions to use depending on the type of water sources being used (Kumwenda et al. 2014). A study in Chikwawa District which has similar climatic conditions with Karonga District showed that the main factors that affect use of water guard include: previous water guard use; availability of water guard in the house; perception about vulnerability to diarrhoea and cholera; perception about water source; and cost (Kumwenda et al. 2014).

5.4 Risk perceptions, Knowledge and Socio-economic Status

5.4.1 Risk perceptions

Results showed that majority of respondents (86%, n = 51) who felt being at high risk of contracting cholera in future were also not very confident of controlling cholera spread. This finding is important in designing of cholera response strategies as argued by Williams et al. (2010) that perception of risk of cholera is vital in crafting strategies for the prevention and response to outbreaks. Findings further showed that respondents were able to mention cholera risk factors like ‘consumption of contaminated food and water’ and ‘poor sanitation and hygiene at home’. This finding showed that respondents were aware of the link between cholera incidences and faeces.

5.4.2 Knowledge about cholera

Results showed that many of respondents (67%, n = 236) had good knowledge about causes and transmission. However, this did not coincide with having good drinking water source quality as out of those who had poor drinking water source quality majority (75%, n = 32) had good knowledge of cholera. This suggests that knowledge about cause, transmission and treatment of cholera alone is not enough to prevent cholera incidence. Perception and myths of cholera are important factors in acceptance and accessibility to ensure effective response in outbreaks as reported in a study by Ujah et al. (2015) in cholera endemic areas of Nigeria.

Though no respondent indicated seeking traditional healers or traditional medicine, Karonga District is well known that traditional healing is a widely-used practice among the Ngonde people. According to Mlenga (2016), in regard to an illness, “it is believed among the Ngonde that natural illness is the one that yields to bio-medical treatment or traditional treatment, and healing is expected to take place immediately or a few days after treatment.” She further writes that “many Ngonde Christians believe that some illnesses cannot be treated bio-medically and must be taken to traditional healers who can heal them. Examples included illnesses that result from angry ancestors or curses from a living parent or guardian, fimbuza {*spirit possession*}, and chikoko.” Ancestral spirits have also long been associated with water by the Ngonde, especially the lake and pools of water within the District. Mackenzie (1925) when describing ancestral spirits writes “on the lake, during a storm, they are still to be heard, demanding a victim to be thrown to them who they may ‘eat.’” This is important, because cholera is a water borne disease. Karonga district also has its own unique cultural practices, whose role in cholera have not been taken into account in the present study. The focus on local socio-cultural practices could prevent people from getting medical care when a person contracts cholera thereby promoting the spread as it relates to knowledge of the people on cause and transmission routes of cholera. Strong economic reliance on Lake Malawi-related activities, deeply rooted patriarchal culture, and practice of polygamy among others are some of the strong and evolving realities within the District (Mlenga 2016). While there are no official statistics for the district available, the Karonga District Council (2013) only reports “there are a lot of polygamous families.”

5.4.3 Socio-economic Status

Findings showed that none of the households who owned four assets and above were using unprotected water sources (Lake Malawi, rivers and unprotected shallow wells). This is in line with findings by Manda and Wanda (2017), who noted that the risks of unsafe sanitation and poor drinking water quality are high among low income households in Karonga District. This is also in line with findings by Irianti et al. (2016) who found that high income households were more likely to use improved drinking water sources in Indonesia. Households in the current study mainly owned phones, bicycles and radios. This was consistent with the 2018 Malawi Population and Housing Census Report (NSO 2019) which also highlights a similar trend to the results of a relatively high percentage of households owning mobile phones, bicycle and radio in that order which are used as a proxy measure of socio-economic status. Cholera patients in the study area had relatively higher asset ownership compared to national and district data.

In terms of drinking water source quality, results showed that poor households had poorest drinking water source quality. Cholera incidences are more prone in areas with poor water quality. Talavera and Perez (2009) noted that low-income areas were more affected by cholera disease than areas with middle or high income. This is also in line with finding by Ali et al. (2017) who found that low income households were more susceptible to cholera risk factors like consumption of unrefrigerated leftover food and drinking water of poor quality in India.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

This chapter presents concluding statements based on results and discussion of the study as well as hypotheses. It also outlines recommendations drawn based on the results and conclusion.

6.1 Conclusion

The study had three research hypotheses: there is a significant difference in microbiological and physico-chemical quality of drinking water used by cholera affected households compared to the local and international standards; there is a significant association between water treatment practices, socio-economic status and type of water sources used by cholera affected households; there is a significant association between human demographics (risk perceptions, cholera knowledge and socio-economic status) and drinking water source quality. Based on the results, the three hypotheses of the study were accepted as the study found statistical differences in thermotolerant coliform levels and physico-chemical quality of drinking water quality for the cholera patients. Further, there is a significant association between household asset ownership versus household water treatment practice. The microbiological quality results suggest that cholera occurrence was not only linked to poor water quality as majority of patients were drinking water of good quality. Other predisposing factors could include eating contaminated food.

This study is the first one linking water quality and water-related behaviours among cholera patients in northern Malawi. The study analysed 120 drinking water samples and survey data linked to 236 cholera patients and results suggest that the problems in Karonga District involve more than just drinking water source quality or cholera patient household safe water treatment practices, knowledge of cholera, and risk perceptions.

Microbiological quality of water was in the range of 0 - >200 cfu/100 ml. There were significant differences in mean thermotolerant coliform levels between water samples that passed drinking water standards (MBS and WHO) and those that did not pass. Further, there were also significant differences in microbiological quality of water across TAs and water source types. Evidence from the study shows that 'improved' drinking water sources did not eliminate the risk of cholera, with 59% of affected patients (*n* = 236) having used an improved water source, revealing that improved water sources were not necessarily providing safe water.

Physico-chemical quality results were in the following ranges: 6 - 9.98 (pH); <5 ->500 JTU (turbidity); 18.8 - 1393µS/cm (electrical conductivity); 9.40 - 696.5 mg/l (total dissolved solids) and 0.02 - 0.70 PSU (salinity). There were significant differences in mean pH, turbidity, EC and TDS between samples that passed and those that did not pass local (MBS) and international (WHO) drinking water guidelines. Further, pH, water temperature, EC, TDS and Salinity varied significantly across TAs and water source types. Mean turbidity varied significantly with regard to water source types.

There was no significant relationship between risk perception and water treatment practice. Further, results showed a statistical association between number of assets owned by a household and water treatment practice. Cholera affected households who own more assets are more likely to treat water at household level compared to those with fewer assets. Both households using protected water source and unprotected water sources had the same likelihood of practicing HWT. However, households using borehole water have a higher likelihood of practicing HWT.

6.2 Recommendations

Based on drinking water quality results and conclusion in the study area, installing improved water sources for the 22 geographic areas with high-risk drinking water quality (>50 cfu/100 ml) is needed. This would require an investment of USD$112,000 based on the costs of manually and mechanically drilled boreholes. The cost of a reactive response to cholera outbreaks puts a burden on Malawi, but provides an opportunity for investment in innovative and localized preventive strategies to control and eliminate the risk of cholera while acknowledging known social and cultural norms. These strategies can include:

- Promoting household water treatment using chlorine and boiling,
- Targeted behavioural change interventions accounting for social and cultural norms, and the proposed addition of new water sources for 22 geographic areas with drinking water of poor quality.

Strategies to improve practice of household water treatment in at risk communities may include:

- Efforts to improve household income so that low-income households can afford HWT products. This may be one of the strategies complementing the existing ones alongside civic education campaigns on the importance of HWT and its associated benefits.

Further research is needed to better understand other causal factors for cholera transmission. Such factors may include safe storage of water, health and hygiene practices, eating contaminated food, and taking water from alternative sources while travelling or working, particularly in the case of fishers. The latter could be significant, as communities often shared a water source and cholera cases were not clustered around unsafe water sources.

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APPENDICES

Appendix A: Research Ethics and Regulatory Approval and Permit by NCST

NATIONAL COMMISSION FOR SCIENCE & TECHNOLOGY

Lingadzi House
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NATIONAL COMMITTEE ON RESEARCH IN THE SOCIAL SCIENCES AND HUMANITIES

REF.NO.NCST/RTT/2/6 **13th August, 2018**

Dr Rochelle Holm
Centre of Excellence in Water and Sanitation
P/Bag 201 Luwinga
MZUZU

Dear Dr R Holm,

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL NUMBER NO. P.07/18/291: WATER QUALITY OF VILLAGES AFFECTED BY CHOLEARA IN KARONGA

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the National Committee on Research Ethics in the Social Sciences and Humanities (NCRSH) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee and the Commission with a final report of the study. The committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms and data collection tools for a period not more than five years.

Wishing you a successful implementation of your study.

Yours Sincerely,

Mike Kachedwa

HEAD OF NCRSH SECRETARIAT
For: CHAIRMAN OF NCRSH

Official Address:
Secretariat, National Committee on Research in the Social Sciences and Humanities, National
Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City,
Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

Appendix B: Oral Informed Consent Form

Centre of Excellence in Water and Sanitation

Mzuzu University

P/Bag 201, Mzuzu 2, Malawi

Oral Informed Consent Form for cholera research, Karonga

As you know, we are working on a study of cholera cases in Karonga. We would like to interview you for about 10 minutes.

You are being invited to take part in this research because you or a family member has recently had cholera.

We would like to use the data for educational and research purposes. It might, for example, be shared with the Ministry of Health, UNICEF or other partners. We might also use the data in reports or papers written about the study. We would ensure that no identifying information about you would be shown in these presentations or reports.

You do not have to answer any question or take part in the survey questions if they make you uncomfortable.

If you would rather not be interviewed, that is fine. Participation in the research is completely voluntary.

Who to Contact

If you have any questions, you can ask them now or later. If you wish to ask questions later, you may contact: Dr. Rochelle Holm, Mzuzu University, Centre of Excellence in Water and Sanitation, P/Bag 201, Mzuzu 2, , Cell: +265992159079 or +265882725730. This proposal has been reviewed and approved by NCST, which is a committee whose task it is to make sure that research participants are protected from harm. If you wish to find about more about the IRB, contact Mr. Mike G Kachedwa, Chief Research Services Officer, Health, Social Sciences and Humanities Division, National Commission for Science and Technology, P.O. Box 30745, Capital City, Lilongwe 3, Malawi, Office Phone: +265 1 771 550/774 869.

Do you have any questions?

Do you have any questions about the purpose of our interview? [*Make note of, and answer, any questions asked.*]

Would you be willing to participate in the interview I have described?

____ Yes

____ No

Appendix C: Water point observational checklist and community questionnaire

Name of Enumerator: ______________________ Date of interviews: ________________

1. Water sources checklist

1.1. Define/Categorise the type of water sources and capture the water source position using GPS (Determine by direct observation only).

No.	Water source	Tick
1	Functional borehole (FBH)	☐ Yes No ☐
2	Functional water kiosk (FWK)	☐ Yes No ☐
3	Functional protected shallow well (FPSW)	☐ Yes No ☐
4	Non-functional borehole (NFBH)	☐ Yes No ☐
5	Non-functional water kiosk (NFWK)	☐ Yes No ☐
6	Unprotected shallow well (USW)	☐ Yes No ☐
7	River	☐ Yes No ☐
8	Lake Malawi	☐ Yes No ☐

1.2. Who owns the water source?

a. Household head name

b. Community

c. Or use water source code

1.3. How many households are served by water source? ________________________

1.4. How many people are served by the water source? ________________________

1.5. Do you do anything to the water to make it safe to drink?

No.	Safety measure	Tick
1	Boil the water	☐ Yes No ☐
2	Use water filter	☐ Yes No ☐
3	Strain it through a cloth	☐ Yes No ☐
4	Add PUR sachet	☐ Yes No ☐
5	Add bleach/chlorine solution	☐ Yes No ☐
6	Let it stand/settle)	☐ Yes No ☐
7	Solar disinfection	☐ Yes No ☐
8	Don't know	☐ Yes No ☐
9	Other	☐ Yes No ☐
Specify		

1.6. Are there any problems with the pump that require attention?

☐ Yes ☐ No

1.7. If yes, what is the problem?

No.	Problem	Tick
1	Broken pipe	☐ Yes No ☐
2	Disjointed rope	☐ Yes No ☐
3	Worn out parts	☐ Yes No ☐
4	Civil works problem	☐ Yes No ☐

5	Low water flow	☐Yes No ☐
6	Low water table	☐Yes No ☐
7	Solar disinfection	☐Yes No ☐
8	Other	☐Yes No ☐
Specify		

1.8. Is it possible to conduct a flow rate today? (You will need a 20-liter bucket).Flow Rate Result_______________ (number of 20 litres filled within a minute)

1.9. Condition of apron (Determine by direct observation only)

No.	Condition	Tick
1	Good (no cracks and no standing water)	☐Yes No ☐
2	Fair (has some cracks)	☐Yes No ☐
3	Poor (has many cracks)	☐Yes No ☐

1.10. Condition of soak away pit (Determine by direct observation only)

No.	Condition	Tick
1	Present and absorbing water (functional)	☐Yes No ☐
2	Not functional	☐Yes No ☐

1.11. Any water lodging around the pump (Determine by direct observation only)

☐ Yes ☐ No

1.12. Any pit latrine within 30m (Determine by direct observation only)

☐ Yes ☐ No

1.13Other comments

2. Cholera cases checklist (Capture cholera case position using GPS)

2.1 Check and indicate Cholera case ID from the Cholera cases line listing file.

2.2 Age of Cholera case (patient)? (check in cholera cases line listing)

____

2.3 Sex of the Cholera case (patient)? (check in cholera cases line listing)

☐ Male Female ☐

2.4 Did you get infected by the disease through contact? (***Tick** where applicable*)

☐ Yes ☐ No

2.5 Date of onset (first symptoms): DD/MM/YY

2.6 Date seen at health facility: DD/MM/YY

2.7 How many days did you spend ate the hospital? _______________

2.8 Did you experience any of the following signs and symptoms?

No.	**Sign/symptoms**	**Tick**
1	Fever	☐ Yes No ☐
2	Abdominal pain	☐ Yes No ☐
3	Diarrhoea	☐ Yes No ☐
4	Vomiting	☐ Yes No ☐

5	Headache	☐ Yes No ☐
6	Loss of appetite	☐ Yes No ☐
7	General body weakness	☐ Yes No ☐
8	Other Signs and Symptoms	☐ Yes No ☐
If yes, specify:		

2.9 Which of the following toilet does your household have? (*Determine by direct observation only + capture position of toilet using GPS)*

No.	**Toilet**	**Tick**
1	Water closet toilet	☐ Yes No ☐
2	Pit latrine, without cement slab	☐ Yes No ☐
3	Pit latrine, with cement slab	☐ Yes No ☐
4	No toilet	☐ Yes No ☐

2.10 If yes, does your toilet have a handwashing facility?(Determine by direct observation only)

☐ Yes ☐ No

2.11 If yes, is the handwashing facility functional and have soap on the visit today? (Determine by direct observation only)

☐ Yes ☐ No

2.12 If it is functional, do you use a soap for washing your hands after using the toilet?

☐ Yes ☐ No

2.13 If yes to Q2.9, does your toilets have a drop-hole cover? (*Determine by direct observation only*)

☐ Yes ☐ No

2.14 Have you received any community messages about building toilets here?

☐ Yes ☐ No

2.15 In your household do you have any of the following assets?

No.	**Asset/s**	**Tick**
1	Bike	☐ Yes No ☐
2	Cell phone	☐ Yes No ☐
3	Radio	☐ Yes No ☐
4	Television	☐ Yes No ☐
5	Cook stove	☐ Yes No ☐
6	Refrigerator	☐ Yes No ☐
7	Car	☐ Yes No ☐

3 KNOWLEDGE ON CHOLERA, PREVENTION, SIGNS AND SYMPTOMS, AND TREATMENT

3.1 What causes cholera?

No.	**Cause**	**Tick**
1	Bacteria (*Vibrio cholerae*)	☐ Yes No ☐
2	Virus	☐ Yes No ☐

3	Wind	☐Yes No ☐
4	Touch	☐Yes No ☐
5	Witchcraft	☐Yes No ☐
6	Bad air	☐Yes No ☐
7	Do not know	☐Yes No ☐
8	Other cause/s	☐Yes No ☐
If yes, specify:		

3.2 How does a person get cholera?

No.	**Means**	**Tick**
1	Consuming contaminated food and water	☐Yes No ☐
2	Poor sanitation when caring for Cholera patient	☐Yes No ☐
3	Poor sanitation and hygiene practices in the home	☐Yes No ☐
4	Do not know	☐Yes No ☐
5	Other mean/s	☐Yes No ☐
If yes, specify:		

3.3 What are the symptoms of cholera? (multiple responses possible)

No.	**Symptoms**	**Tick**
1	Cloudy watery stool	☐Yes No ☐
2	Vomiting	☐Yes No ☐
3	Loss of skin elasticity	☐Yes No ☐
4	Dehydration	☐Yes No ☐

5	Fever	☐Yes No ☐
6	Sunken eyes	☐Yes No ☐
7	Do not know	☐Yes No ☐
8	Other symptom/s	☐Yes No ☐
If yes, specify:		

3.4 Can people be treated for Cholera? (***Tick*** *where applicable*)

☐ Yes ☐ No

3.5 How is cholera treated? (Multiple responses possible). Skip if N/A

No.	**Means of treatment**	**Tick**
1	Go to clinic/health facility	☐Yes No ☐
2	Use ORS/sugar-salt solution	☐Yes No ☐
3	Go to Cholera treatment centre	☐Yes No ☐
4	Home remedy	☐Yes No ☐
5	Go to clinic/health facility	☐Yes No ☐
6	Do not know	☐Yes No ☐
7	Other	☐Yes No ☐
If yes, specify:		

3.6 How do you prevent cholera? (multiple responses possible)

No.	**Means of prevention**	**Tick**
1	Use of sanitary toilet/latrine	☐Yes No ☐

2	Treat drinking water	☐Yes No ☐
3	Good hygiene practices in the home	☐Yes No ☐
4	Washing hands with soap after defection	☐Yes No ☐
5	Wash hands before preparing food	☐Yes No ☐
6	Protection of food (taking fresh food and avoiding rotten food)	☐Yes No ☐
7	Proper disposal of excreta refuse	☐Yes No ☐
8	Disinfect all contaminated items	☐Yes No ☐
9	Use of sanitary toilet/latrine	☐Yes No ☐
10	Treated water handling techniques include two cup system	☐Yes No ☐
11	Do not know	☐Yes No ☐
12	Other means of prevention/s	☐Yes No ☐
If yes, specify:		

3.7 What are the immediate steps to take when one is showing signs and symptoms of Cholera? (multiple responses possible)

No.	**Steps**	**Tick**
1	Isolate the patient	☐Yes No ☐
2	Rehydrate	☐Yes No ☐
3	Go to treatment centre	☐Yes No ☐
4	Do not know	☐Yes No ☐
5	Other step/s	☐Yes No ☐

If yes, specify:

4 ATTITUDES

4.1 What level of risk do you think you have in getting cholera?

No.	Level of risk	Tick
1	No risk	☐Yes No ☐
2	Low risk	☐Yes No ☐
3	Medium risk	☐Yes No ☐
4	High risk	☐Yes No ☐
5	Don't know	☐Yes No ☐

4.2 How confident are you that your village/community/area can control the spread of cholera if there was another outbreak in the future?

No.	Level of confidence	Tick
1	Extremely confident	☐Yes No ☐
2	Somewhat confident	☐Yes No ☐
3	Not very confident	☐Yes No ☐
4	Do not know	☐Yes No ☐

5 EXPOSURE TO CHOLERA PREVENTION INTERVENTIONS

5.1 Have you had cholera communication initiatives in your community? (***Tick** where applicable*)

☐ Yes ☐ No

5.2 Have you participated in any cholera communication prevention activity lately? (***Tick** where applicable*)

☐ Yes ☐ No

5.3 How have you participated in any cholera prevention activity this year? (Skip if N/A)

No.	Means of participation	Tick
1	HSA meetings	☐ Yes No ☐
2	Community dialogue sessions	☐ Yes No ☐
3	House to houses visits	☐ Yes No ☐
4	Road shows	☐ Yes No ☐
5	Distribution of posters/fliers/print IEC materials	☐ Yes No ☐
6	Community drama	☐ Yes No ☐
7	Cholera vaccination	☐ Yes No ☐
8	Community cinema	☐ Yes No ☐
9	Other means of prevention/s	☐ Yes No ☐
If yes, specify:		

5.4 What organisations have been disseminating cholera messages in your community?

No.	Organisations	Tick
1	CDC	☐ Yes No ☐
2	Story Workshop	☐ Yes No ☐
3	PACHI	☐ Yes No ☐

4	EXP	☐Yes No ☐
5	UNICEF	☐Yes No ☐
6	Face to Face (STEPS)	☐Yes No ☐
7	Malawi Red Cross	☐Yes No ☐
8	World Vision	☐Yes No ☐
9	United Purpose	☐Yes No ☐
10	PDI	☐Yes No ☐
9	Other organisation/s	☐Yes No ☐
If yes, specify:		

6 EXPOSURE TO CHOLERA MESSAGES

6.1 What is your primary source of information on cholera?

No.	Source	Tick
1	Community health workers/HSA	☐Yes No ☐
2	Hospital	☐Yes No ☐
3	Radio	☐Yes No ☐
4	Television	☐Yes No ☐
5	Community cinema	☐Yes No ☐
6	Roads shows	☐Yes No ☐
7	IEC materials	☐Yes No ☐
8	Drama	☐Yes No ☐
9	Don’t know	☐Yes No ☐
9	Other source/s	☐Yes No ☐

If yes, specify:

6.2 Have you ever heard of preventing and treating Cholera in **last 3 months**? (***Tick*** *where applicable*)

☐ Yes No ☐

6.3 What were the messages heard? (Skip if N/A)

No.	Message heard	Tick
1	Wash hands with soap at all critical times	☐Yes No ☐
2	Use toilet and latrines for disposal of fences	☐Yes No ☐
3	Drink only safe water (boiled or treated)	☐Yes No ☐
4	Cover food and reheat leftover food before eating	☐Yes No ☐
5	Continue breastfeeding babies and ensure your child gets plenty of liquids when they have diarrhoea	☐Yes No ☐
6	Take under 5 children to the health clinic as soon as they observe diarrheal signs	☐Yes No ☐
7	Do not know	☐Yes No ☐
8	Other message/s heard	☐Yes No ☐
If yes, specify:		

End of Questions