# Assessment of factors affecting adoption of rooftop rainwater harvesting technology for domestic use in Blantyre, Malawi


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


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# DECLARATION

I hereby declare that this thesis titled, "Assessment of factors affecting adoption of rooftop rainwater harvesting technology for domestic use in Blantyre, 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 Resource Management and Development at Mzuzu University. None of the present work has been submitted previously for any degree or examination in any other University.

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Chrissie Msulira Banda Date

## CERTIFICATE OF APPROVAL

I, the undersigned, certify that this thesis is a result of the author's own work, and that to the best of my knowledge, it has not been submitted for any other academic qualification within Mzuzu University or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on Date: 20th March 2020.

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# ABSTRACT

Despite widespread perception that harvested rainwater from rooftop has poor quality, rooftop rainwater harvesting remains an option for ensuring access to safe drinking water. This study assessed factors affecting adoption of rooftop rainwater harvesting technology for domestic use. The study used simple random sampling to select 150 households. Data was collected from Nancholi area in Blantyre City, with questionnaires and check lists used as data collection tools. Additionally, water samples from 100 households of adopters of Rooftop Rainwater Harvesting were collected and measured using standard methods and equipment. The collected data were analyzed using SPSS 16.0. The results on Chi- square test showed that there was no significant difference in roof catchment and differences ($p<0.05$) in supporting collecting system, storage devices and storage capacity of rooftop rainwater harvesting systems among households. On suitability for drinking, the pH, free chlorine, total chlorine, and total dissolved solids met the minimum requirements of the Malawi Bureau of Standards (MBS, 2013) for drinking water. However, thermotolerant coliform and turbidity did not meet the requirements of the MBS because it contained dirty, debris and bird feacal matter. The results on Binary logistic regression test indicates that household size, household perception and household income have significant relationship to the probability for adoption. However, it was found that water source, access to information, and distance to water source registered an insignificant relationship ($p>0.05$) with the probability of the adoption. The study found that harvested rooftop rainwater is not suitable for direct drinking since it contains microbes. When harvested rooftop rainwater is intended for drinking, water treatment like boiling and use of water guard should be promoted.

**Keywords**: Blantyre, household, rainwater, urban, water quality.

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# ACRONYMS

| | |
|---|---|
| BWB | Blantyre Water Board |
| CFU | Colony-forming unit |
| JTU | Jackson Turbidity Unit |
| MBS | Malawi Bureau of Standards |
| NDWQS | National Drinking Water Quality Standards |
| NGO | Non-Governmental Organization |
| NSO | National Statistical Office |
| RRWH | Rooftop Rainwater Harvesting |
| RRWHT | Rooftop Rainwater Harvesting Technology |
| SDGs | Sustainable Development Goals |
| SPSS | Statistical Package for the Social Sciences |
| TDS | Total Dissolved Solids |
| UNICEF | United Nations Children Fund |
| WASH | Water, Sanitation and Hygiene |
| WHO | World Health Organization |

# TABLE OF CONTENTS

**DECLARATION** .......... **i**
**CERTIFICATE OF APPROVAL** .......... **ii**
**ABSTRACT** .......... **iii**
**ACRONYMS** .......... **v**
**TABLE OF CONTENTS** .......... **vi**
**LIST OF TABLES** .......... **viii**
**LIST OF FIGURES** .......... **ix**
**CHAPTER 1: INTRODUCTION** .......... **1**
1.1 Background of the study .......... 1
1.2 Problem statement .......... 3
1.3 Study objectives .......... 4
1.4 Justification of the study .......... 5
1.5 Ethical consideration .......... 6
**CHAPTER 2: LITERATURE REVIEW** .......... **7**
2.1 Description and history of rainwater harvesting technology .......... 7
2.2 The system of RRWHT .......... 9
2.3 Rooftop rainwater quality for drinking and household use .......... 11
2.4 Factors affecting adoption of roof rainwater harvesting technology .......... 12
**CHAPTER 3: MATERIALS AND METHODS** .......... **15**
3.1 Study area .......... 15
3.2 Research design .......... 17
3.3 Sampling framework and methods .......... 18
3.4 Data collection .......... 19
3.5 Data management and statistical analysis .......... 21
**CHAPTER 4: RESULTS** .......... **24**
4.1 The system of RRWH among households .......... 24
4.2 Rooftop rainwater quality for drinking and domestic use .......... 25
4.3 Factors that affect adoption of RRWH .......... 31
**CHAPTER 5: DISCUSSION** .......... **33**

5.1 The system of RRWH among households .................................................................... 33
5.2 Rainwater quality for drinking and domestic purposes.................................................. 35
5.3 Factors that affects adoption of RRWHT........................................................................ 40
**CHAPTER 6: CONCLUSION AND RECOMMENDATIONS ........................................... 44**
6.1 Conclusion.......................................................................................................................... 44
6.2 Recommendations ............................................................................................................. 45
6.3 Areas of further study........................................................................................................ 45
**CHAPTER 7: REFERENCES ................................................................................................ 46**
Appendix A: Ethical Clearance ............................................................................................. 59
Appendix B: Household Questionnaire ................................................................................ 60
Appendix C: Informed Consent Form for Research ............................................................ 66
Appendix D: List of random numbers for RRWH adopters ................................................ 70
Appendix E: List of random number for non RRWH adopters .......................................... 73
Appendix F: Components of system design of rooftop rainwater harvesting ..................... 75
Appendix G: Distribution of parameters among households............................................... 77

## LIST OF TABLES

Table 1: Summary of materials and methods. .................................................................. 23

Table 2: Determination of system designs of rooftop rainwater harvesting technology. ............. 24

Table 3: Suitability of rainwater for drinking. .................................................................. 31

Table 4: Factors affecting adoption of rooftop rainwater harvesting technology. ........................ 32

## LIST OF FIGURES

Figure 1: Rooftop rainwater harvesting system (Amin & Alazba, 2011) ........................................ 8

Figure 2: Rooftop rainwater harvesting system (Doctor et al, 2018) ........................................... 10

Figure 3: Study area, Nancholi, Blantyre, Malawi. ...................................................................... 16

Figure 4: The pH levels................................................................................................................. 25

Figure 5: Alkalinity levels. ........................................................................................................... 26

Figure 6: Total hardness levels. .................................................................................................... 27

Figure 7: Free chlorine levels. ...................................................................................................... 27

Figure 8: Total chlorine levels. ..................................................................................................... 28

Figure 9: Total dissolved solids. ................................................................................................... 29

Figure 10: Turbidity levels............................................................................................................ 29

Figure 11: Thermotolerant coliform levels. .................................................................................. 30

# CHAPTER 1: INTRODUCTION

The chapter contains information on the study background, problem statement, study objectives, hypothesis, study justification and ethical consideration for the research on assessment of factors affecting adoption of Rooftop Rainwater Harvesting Technology (RRWHT) for domestic use.

## 1.1 Background of the study

The World Health Organizations (WHO) and the United Nations Children's Fund (UNICEF) (2017) report that, worldwide, 2.1 billion people lack access to potable water supplies and 2.3 billion people have inadequate basic sanitation facilities. WHO/UNCEF (2017) indicates that in Malawi only 67% of the population has the opportunity of accessing basic water supplies that is regarded safe and clean. In most developing countries, including Malawi, child education is interrupted and important livelihood activities such as agriculture and business are also affected as people tend to wake up early in the morning and walk long distances to access safe drinking water (Chipeta, 2009).

The Sustainable Development Goal (SDG) 6 emphasises on “ensuring availability and sustainable management of water and sanitation for all” (United Nations 2016). However, Blantyre City residents are supplied with piped water by the Blantyre Water Board. The water quantity is inadequate for the entire City due to urbanisation, high population, frequent broken down of conveyance pipes and climate change (Maoulid, 2012). In cases of inadequate piped water supply, people search for other alternative water sources, such as rainwater, in order to meet their daily water demand.

One potential means of ensuring availability and sustainable access to potable water in urban areas, especially during the rainy season, is the use of rainwater harvested from roofs (commonly known as Rooftop Rainwater Harvesting (RRWH) (Jankar and Bhanuse, 2013). The RRWH is the collection of rainwater from rooftops and stored for household use such as drinking cooking, cleaning houses, washing clothes and bathing (Mwakilembe, 2013). The system of RRWH is mainly composed of roof catchment, conveyance system and storage devices. The roof catchments are made of iron sheets, aluminium, and galvanised Conveyance system is used for transporting water from roof to storage. The conveyance system, for example, gutters are made of plastic and iron sheet pieces and are in different shapes like rectangular, semi-circle and v-sharp (Isaak 2011). Rainwater harvesting does not reduce amount of water that goes into ecosystem.

There are differences in catchment areas between roof catchment and surface area. The amount of rainfall received on roof catchment is less as compared to the surface area, hence, more water goes into ecosystem (Dwivedi and Bhadauria 2009). Rooftop rainwater harvesting have impacts on lives by promoting access to safe and clean water, promoting infiltration, promoting children education since women and children do not walk long distance to fetch water (Mwamila et al. 2016) and Promoting household sanitation. In Malawi, the RRWH is promoted and abstraction rights are provided (Malawi National Water Policy 2005). The RRWH technology is consistent with the climate justice values. It ensures the equal treatment and provides freedom to any type of decimation against negative of climate change. Compared to ground or surface water, the quality of rooftop harvested water is reported to be relatively clean, as there is a negligible contact with the soil surface, where pollutants and mineral salts are dissolved (Saraswat and Kumar 2016).

Chowdhury et al. (2015) state that rainwater is bacteriological free from organic matter and naturally is soft. The harvested rainwater quality is affected by environment conditions such dirty and debris deposited on the roof catchments between rainfall events. The quality of harvested rainwater is also affected by meteorological conditions such as temperatures, dry periods and rainfall patterns (Ghaleb et al. 2018). Pichlak (2015) define adoption as a process by which technologies are communicated thereafter accepted and implemented. Many households adopted the technology that has more benefits. Despite Non-Governmental Organizations (NGOs) promoting rainwater harvesting as a solution to the growing problem of water shortages. The adoption rate of the RRWHT in Malawi is at 0.2% in towns and City residents (Wiyo 2014). Therefore, the study assessed factors affecting adoption of rooftop rainwater harvesting technology for domestic use.

### 1.2 Problem statement

There is low adoption rate of the RRWHT for domestic use in Malawi. The low adoption is caused due to perception of households on rainwater quality, inadequate financial resources, availability of water source and improper standards of the RRWH system (Wiyo, 2014 & Goyal, 2014). Communities believe that the harvested rainwater produces smell, bad colour and poor taste (Tobin et al., 2013). Additionally, the reason why communities do not use harvested rainwater is that there is a perception that rainwater is not safe for drinking and domestic use (Daoud et al., 2011). They also believe that rainwater is associated with water related diseases such as diarrhoea and dysentery (Shalamzari et al., 2016). Instead, communities get additional water from unprotected water source e.g. rivers other than the RRWH. The unprotected water sources contain microbes which cause water related diseases like cholera (Chipeta, 2009).

The analysis of water quality for drinking and domestic use is the only way of establishing whether the water at a particular water source is safe and clean. Therefore, the study investigated the quality of rooftop rainwater to understand if harvested rainwater source is safe and clean for drinking and domestic use. Few studies have been conducted on the RRWH systems, rainwater quality for domestic use and factors that affect adoption of the RRWHT in Malawi. Among the few studies, Wiyo (2014) conducted a study on Policy and Institutional Challenges in promoting rainwater harvesting for domestic use in Malawi's Cities and towns. There is no scientific evidence to determine the RRWH systems, harvested rainwater quality and factors affecting adoption of the RRWHT. This study was specifically designed to fill this gap by investigating the system, rainwater quality and factors affecting the adoption of the RRWH in Malawi.

## 1.3 Study objectives

The study was guided by the following main and specific objectives:

### *1.3.1 Main objective*

The main objective of the research was to assess factors affecting adoption of rooftop rainwater harvesting technology for domestic use, in Blantyre, Malawi.

### *1.3.2 Specific objectives*

The study specifically addressed the following objectives:

a) To determine the existing system of rooftop rainwater harvesting among households.

b) To analyse the quality of rooftop harvested water for drinking and domestic purposes in relation to drinking water quality set by the Malawi Bureau of Standards (2013).

c) To identify factors that influence adoption of rooftop rainwater harvesting technology.

### *1.3.3 Hypotheses*

The study was based on the following hypotheses:

a) There is no significant difference in roof catchment, supporting collecting system, storage devices and storage capacity of rooftop rainwater harvesting among households.

b) There is no significant difference in water quality of rooftop harvested water and water quality levels against guidelines by the Malawi Bureau Standards (2013).

c) There is no significant relationship between household size, household perception, water source, water source distance, access to information, household income and adoption of rooftop rainwater harvesting technology.

## 1.4 Justification of the study

Findings from this study will help decision makers as well as development organizations in identifying factors to be considered when promoting the RRWH for drinking and domestic use at household level, especially in low-income urban areas with interrupted piped water supply. The study findings will also help to clear myths and misunderstandings on rainwater quality since many believe that harvested rainwater is of poor quality. In regards to water quality, the study results will ignite and add to the continuing debate on the use of conventional piped water supplied by the Blantyre Water Board (BWB) in comparison to rainwater that is harvested. The findings of this study have potential to expose further areas of study on water quality of harvested rainwater and factors that affect adoption of the RRWH. The research in the two areas mentioned is not widely conducted in Malawi. The results will contribute to the promotion of proper system design of the RRWH for all households at all levels.

## 1.5 Ethical consideration

The research was approved by the Malawi Government, National Commission for Science and Technology (NCST) (Protocol No: P.12/17/236) and the Mzuzu University Faculty of Environmental Sciences Research Committee. Written informed consent (Appendix A) was obtained from officials in the study area and households before interviews and observations were conducted.

# CHAPTER 2: LITERATURE REVIEW

This chapter presents literature review on history of rainwater harvesting technology, system of rooftop rainwater harvesting, harvested rainwater quality and factors that influence adoption of rooftop rainwater harvesting technology.

## 2.1 Description and history of rainwater harvesting technology

The RRWH involves collecting and storing rainwater from buildings roofs for domestic use and is used to increase water supply for household use (Yosef & Asmamaw, 2015; Kimani et al., 2015). In sub-Saharan African, the RRWH has assisted in reducing pressure on current water suppliers (Feyisa 2014). Further, the harvesting of water from roof is a simple and low-cost system for combating water related poverty (Shalamzari et al., 2016). The RRWH is the collection of precipitation falling and the concentration of this precipitation for productive activities such as domestic use (Chandel & Sharma, 2014). As described by Chidamba (2015), rooftop water harvesting is one of the categories of domestic rainwater harvesting. When raining, water is collected from roofs and stored in the storage vessels (Shalamzari et al., 2016).

The design of the RRWH systems typically aims to support households with both drinking and cooking water as well as domestic use. The most common RRWH systems that are used are constructed with three basic components namely: 1.) catchment area such as a roof, 2.) a conveyance method which leads from the catchment, such as a gutter, and 3.) a storage holding device where the conveyance leads into usually by gravity, for example a tank (Janker and Bhanuse 2013). As described by Amin and Alazba (2011) simple rooftop rainwater harvesting system consists of catchment area, a treatment facility, a storage tank, a supply facility and piping.

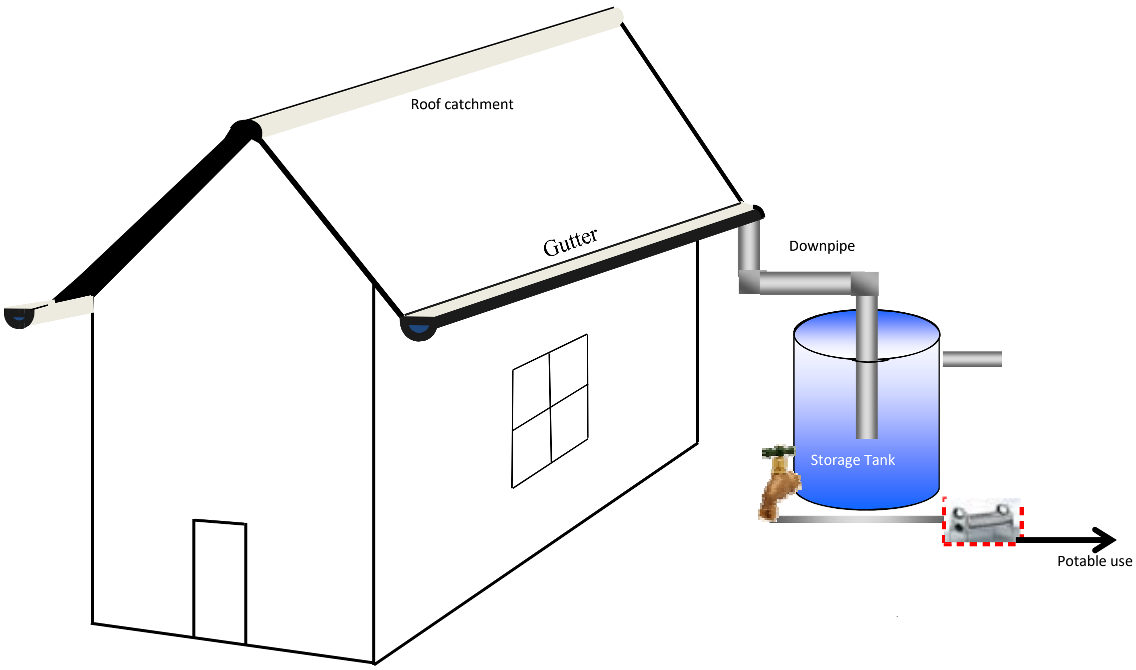


**Figure 1:** Rooftop rainwater harvesting system (Amin & Alazba, 2011).

The RRWH provides an opportunity to ensure water for drinking and domestic use during water scarce seasons. Currently, in countries like China (Gansu province) and Brazil (Semi-arid north), rainwater serves as a main source of drinking water. In ancient years in Baluchistan (now province of Pakistan, Iran and Afghanistan), rainwater harvesting technology was practiced to obtain water for drinking. In Tamil Nadu (now India), King Chola used to harvest rainwater using the roof of Brihadeeswara temple, where a tank from Shivaganga was installed for water collection and storage for drinking and domestic use (Morey et al., 2016).

## 2.2 The RRWHT system

The RRWH system is composed of roof catchment area, supporting collecting system and storage tank. Roof catchment is constructed using different materials including iron sheets and tiles galvanised. Supporting collecting system are gutters and collecting vessels. The gutters are made of plastic, metal or bamboo (Biwas & Mandal 2014). Ojha and Gupta (2016) state that RRWH system is composed of roof catchment for rainwater collection, gutters and downpipes for transportation from roof to tank, leaf screens and roof waters used for removing contaminants, storage tank, conveyance system for delivery and water treatment. Mohite and Lole (2014) pointed out that RRWH system is composed of roof catchment, course mesh, gutters, pipeline, first flush, filters and tank. The RRWH is made of roof surface, gutters, down pipes and storage (Doctor et al, 2018).

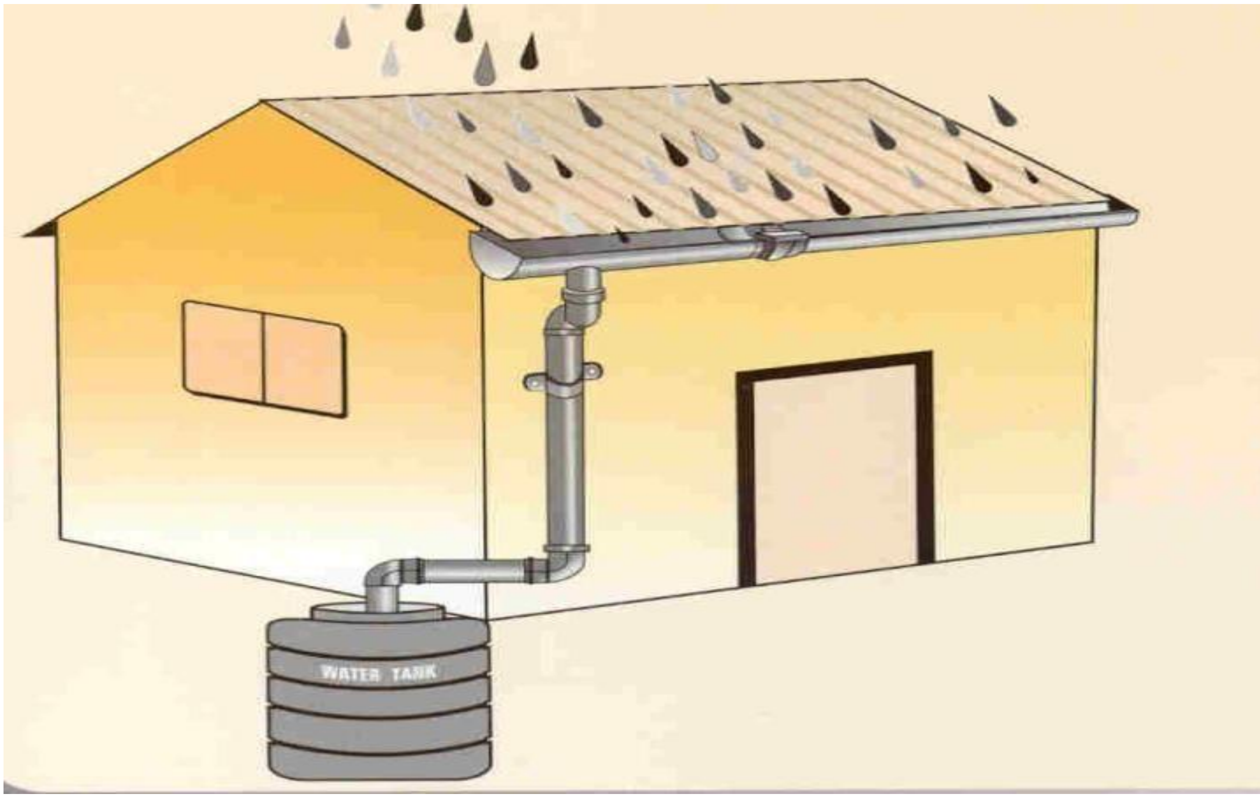


**Figure 2:** Rooftop rainwater harvesting system (Doctor et al, 2018)

The system of RRWH under medium scale consists of roof catchment made of iron sheets, aluminium and tiles, gutters and drop-down pipes made of plastic and aluminium, water quality improvement structures like roof washers or filters are fixed (Bangale et al., 2018). In Tamil Nadu, Indian, rainwater harvesting tanks of $23m^3$ is enough for the maximum storage of water to use during dry season. The amount of rainfall can be harvested to supply a minimum of 20 litres of water per person per day by installing the tank in catchment area of 50 $m^2$ (Jain et al. 2015). The households that adopted the RRWHT uses storage devices made of plastic, concrete, and wood. The storage devices which are used to store harvested rainwater are mounted outside the house. The storage capacity used are ranged from 2000 litres to 10000 litres (Shittu et al., 2015). The small scale or traditional RRWH is made of cheap and locally available materials. For example, roof catchment is made up of grass as well as iron sheets. The gutters are made of iron sheets and PVC pipes. The first flush is made using local and cheap materials such as Jerry cans (Chaplin & Legge, 2019). For small scale category of the RRWH, they use kitchen utensils as storage devices that have capacity of less than 2000 litres (Shittu et al., 2015).

### 2.3 Rooftop rainwater quality for drinking and household use

The quality of the harvested rooftop rainwater is affected by environmental conditions (biological, physical, and chemical) of the location. The microbiological species like *Comamonadaceae*, *Curvibacter,* and Planctomycetaceae, *Brisbane* and *Currrumbin* have been shown to be present in rainwater harvested from rooftops. The presence of these species indicates bird faecal contamination (Hamilton et al., 2017). The heterotrophic bacteria, faecal coliform, *Camplobacter, pseudomonas, Acinetobacter* and *Aeromonas, E. coli, Salmonella spp,* and *enterococcus* have been shown to be found in harvested rooftop rainwater (Jongman & Kursten, 2016; Tobin et al., 2013).

Rainwater harvested from roof has been reported to be contaminated with human pathogens like *Campylobacter, Ligionella, Cryptosporidium* and *Giardia* (Schets et al., 2011; Despins et al., 2009). In another study in Pakistan, rooftop rainwater contained high concentration of magnesium and nitrates due to air pollution (Chughtai et al., 2014).

In Malaysia, levels of pH, turbidity, total dissolved solids, salinity, nitrate oxide, sulphuric acid, zinc and lead met minimum requirements while chlorine parameters exceeded the standards (Payus and Meng 2015). In Ibadan, Nigeria, levels of hardness, alkalinity, chloride, iron, pH and nitrate met the guideline values of the World Health Organization for drinking water (Shittu et al., 2015). Rainwater harvested from different roof materials has no significant effect on water quality (Odoh & Jidauna 2013). Similarly, Ezemonye et al. (2016) state that there are no significant differences between samples of rainwater harvested from different roof catchment types for example, galvanised iron, aluminium and asbestos. All samples were contaminated with microbial parameters, however, the average concentration of iron, chromium, nitrogen and zinc in rainwater that was harvested from a rusted roof was higher than from a non-rusted roof. Contrary to other findings, Olaoye and Olaniyan (2012) stated that thermotorelant coliforms were present in rooftop rainwater samples harvested from asbestos, concrete, and corrugated plastic roofs (Gupta et al., 2016).

## 2.4 Factors affecting adoption of roof rainwater harvesting technology

Nato et al., (2016) state that group involvement and support from the government has a significant effect on the adoption of technologies, while social networks and social trust were reported to negatively influence the adoption of rainwater harvesting technologies. Capacity building in RRWH programmes is the tool to reinforce group participation and spreading of the technologies. In South Africa, lack of finances and an absence of a main coordination body are challenges that prevent adoption of rainwater harvesting technologies, while availability of rainwater harvesting knowledge, biophysical and socio-economic impact of rainwater harvesting are opportunities for promotion (Kahinda et al., 2007). In Makueni County, Kenya, the adoption of rainwater harvesting was also slow and was linked to social, gender, level of education, knowledge of technology and economics. While low education levels among households, inadequate follow up by experts in providing technical and financial support were found to have a negative effect on the adoption of technology (Kimani et al., 2015).

In South Africa, the perception towards the rainwater harvesting technology, gender, age, level of education, income of the household and frequently interacting with extension workers were found to be positively related to the adoption of rainwater harvesting (Baiyegunhi, 2015). The age of the person who earns money to support their family, level of education, land holding size, distance between home and water source and distance to an extension worker all have a significant effect on the choice of adopting rainwater harvesting for household use (Mume & Kamel, 2014). In Ethiopia, the age of respondents, income of the household, water supply quality and quantity perception, lower cost of the technology, ownership of the house and people's attitude are positively related to the adoption of rainwater harvesting technology (Alemayohu 2013). At Thumelat in Limpopo province the adoption decisions by people were significantly and positively related to size of land, access to information, credit and contact with extension workers. The household size and level of education showed a significantly negative relationship to the adoption of technology (Badisa, 2011).

On the negative side, domestic rainwater harvesting storage vessels can be a breeding area for vectors such as mosquitoes that cause malaria. The other factor that contributes to low adoption of rainwater harvesting is the high cost of installing and maintaining domestic rainwater harvesting systems (Kahinda et al., 2007). Commenting on the implementation of rainwater harvesting initiatives, Campisano et al. (2017) state that implementation and technology selection of rainwater harvesting is affected by economic problems and local regulations that govern the use of the technology. Peters et al. (2016) argue that socio-economic factors, level of financial assistance, poor maintenance of water harvesting structures and legislation supported by institutional and organization arrangements can contribute to the failure or success regarding adoption of rainwater harvesting technology. Taffere et al. (2016) highlighted poor design, size of family, demand for water, surface area of the rooftop and size of storage tank as factors that can negatively affect the adoption of rainwater harvesting from roofs for domestic use in Maleke village in Ethiopia. Further, factors that influence the adopters and non-adopters of rainwater harvesting for domestic use are lack of experience and observation (Shalamzari et al., 2016). The age of household, labour and credit have a negative effect on adoption of water harvesting technology (Akrouch et al., 2017).

Factors such as poor quality of harvested rainwater and lack of technical aspects of water harvesting technology contribute to a low sustainable development of water harvesting for household uses (Neibaur & Anderson, 2016). The membership of community and physical assets can contribute to an increase household income. In Addis Ababa, Ethiopia, financial resources are one of the main challenges for the RRWHT as in order to harvest more water one is required to purchase and install large storage devices. These storage devices are expensive as a result they limit the adoption of rooftop water harvesting (Adugna et al., 2018).

# CHAPTER 3: MATERIALS AND METHODS

This chapter presents information on characteristics of the study area, research design, sampling framework and methods, data collection and data management and statistical analysis.

## 3.1 Study area

### 3.1.1 Geographical location

The study was conducted in Blantyre City, within Nancholi Township (Figure 3), in the southern region of Malawi. It is located at an elevation of 112 metres above sea level and across latitudes 9° to 15° S in eastern southern Africa. Malawi is located in the southern part of Africa and surrounded by three countries namely: Zambia, Tanzania and Mozambique (Kumbuyo et al., 2014).

### 3.1.2 Demography and settlement pattern

Blantyre City is Malawi's commercial city and has a household population of 191,676. The city has a total population of 800, 264 (male 401172 and female 399092) (NSO, 2018). The majority of residents live in informal settlements (UN-HABITAT, 2011).

### 3.1.3 Social – economic activities

The Blantyre City have population of different tribes like Chewa, Tumbuka, Yawo, Sena, Tonga and others. The most dominated tribe is Lomwe. The City is the commercial as well as industrial capital of Malawi. The most economic sectors in the city include finance, retail trade, construction, transport, food, textile manufacturing, motor vehicle sales and maintenance, and the informal sector (UN-HABITAT, 2011).

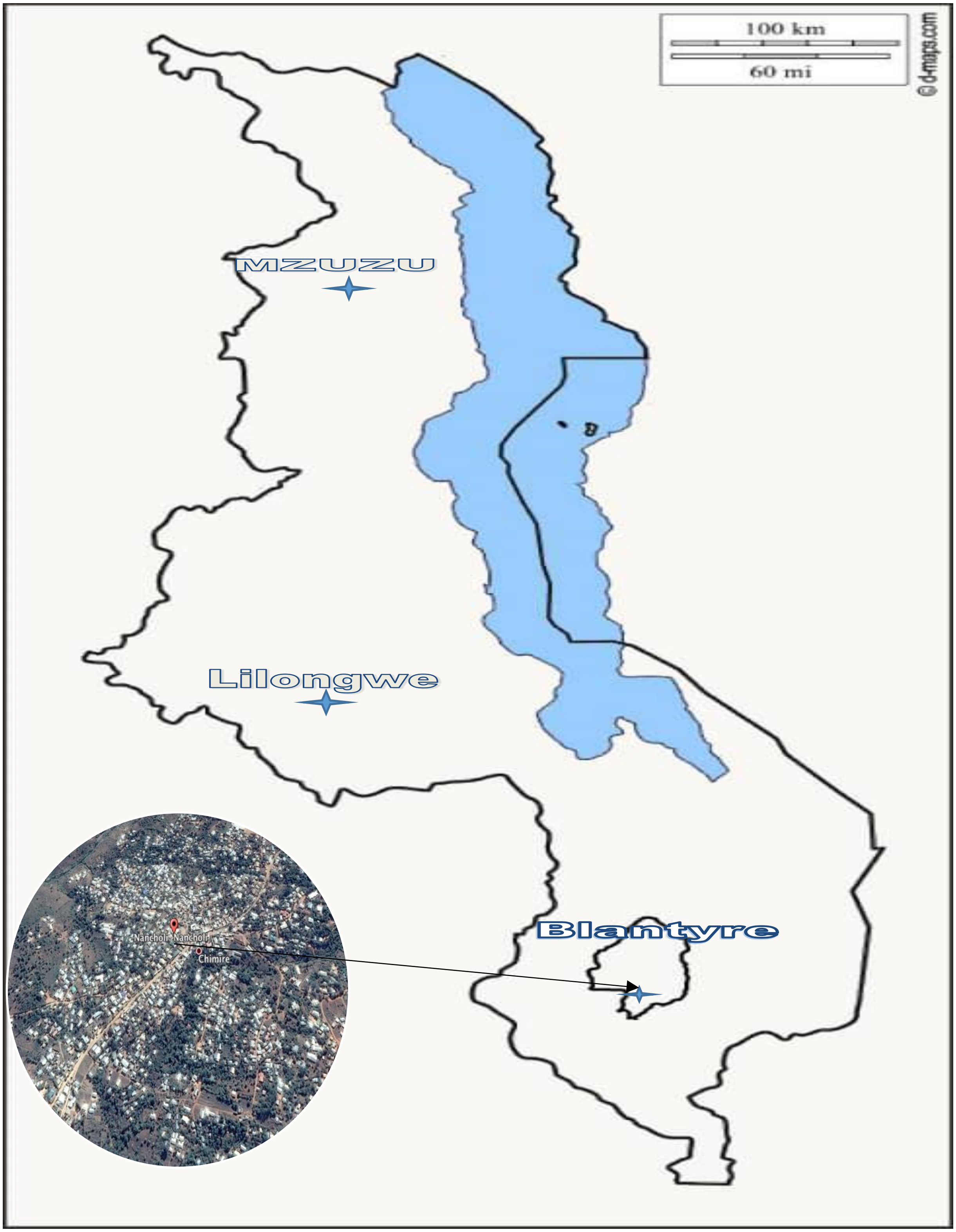


**Figure 3:** Study area, Nancholi, Blantyre, Malawi.

### 3.1.4. Water and sanitation

The main water sources in the study area are kiosks, borehole, piped water and surface water rivers. Piped water is supplied by Blantyre Water Board through both kiosks and piped water, though there is intermittent water supply for each household). Majority of residents in the study area use on-site sanitation system (Maoulidi, 2012.

### 3.1.5 Weather and climate

Malawi has a sub-tropical climate, which is dry and wet seasonal. Annual average rainfall varies from 725 to 2500 mm and Blantyre receives average rainfall amount 1127mm. The wet season rainfall depends on the position of the Intertropical Convergence Zone (ITCZ), which vary according to its timing and intensity from year to year (McSweeney et al., 2012). The other system of rain-bearing for Malawi is the northwest monsoon. This type comprised of recurved tropical Atlantic air that reaches Malawi through the Congo basin. The country is affected by tropical cyclones from Indian Ocean. The cyclones usually result in either dry or wet spells. Easterly waves originating near Madagascar often penetrate through Zambezi valley during summer. Extra-tropical westerly waves are thought to be most active at the beginning and end of the rainy season (Kumbuyo et al., 2014).

## 3.2 Research design

The study used a quantitative and qualitative survey approach where two populations of adopters and non-adopters of the RRWH were selected. This study used surveys, focus group discussion, observations, field trials and interviews. The quantitative methods assisted in the identification of relationships between the adoption of RRWHT and factors that affect adoption of the technology.

Qualitative research was achieved through conducting household survey and observations on the system of the RRWH. The study design helped to acquire information on RRWH system , rooftop harvested rainwater quality and factors that affects adoption of the RRWH. In additional, the research design helped to obtain information and establish opportunities to promote RRWH.

## 3.3 Sampling framework and methods

In Phase I, in order to develop a census of the households in the study area, each household was visited in 2018 and the household head was asked if any rainwater was being collected by their household. GPS readings of the study sites were also taken. From the Phase I results, households were listed and sorted by whether or not they practiced rainwater harvesting. To generate a list of households to be sampled, the random number generator, excel rand formula within Microsoft's Excel program was used to select a sample of households for Phase II. The excel rand formula used = a + (b - a) * RAND (Government Finance Officers Association 2016). For Phase II, the study comprised a total population of 150 households, where 100 households were adopters and 50 were non-adopter households as a representative portion of the study area population. This study targeted more adopters than non-adopter because it was necessary to get as much information as possible from the adopters. In addition, it was assumed that the adopters have more knowledge of rooftop rainwater harvesting than non-adopters since they are practicing it. The sample size was calculated using the formula below (Taherdoost, 2017).

$$n = \frac{p(100 - p)z^2}{E^2}$$

where n = sample size, E = Error, P = Occurrence percentage, Z = Confident interval

## 3.4 Data collection

### *3.4.1 Water quality data*

The field study was conducted from December 2017 to February 2018 during the rainy season. Data collection was done in two phases: Phase I involved the collection of GPS readings of each household whether practicing RRWH or not. In Phase II, harvested rainwater samples were collected and analysed for a wide range of water quality parameters namely total alkalinity, pH, total hardness, free chlorine, total chlorine, total dissolved solids, turbidity and thermotolerant coliform. All these parameters were selected because they are the most commonly used parameters when determining water quality for drinking and domestic use. A total of 100 harvested rainwater samples from rusted roofs and non-rusted roofs were collected. The harvested rainwater samples were collected in two whirl-pak sterilized water sampling bags that contained sodium thiosulfate as a preservative. The thermotolerant coliform samples were taken to laboratory for analysis.

For determination of levels of total alkalinity, pH, free chlorine, total chlorine and total hardness, water samples were analysed with Hatch Aqua check 5 in 1 (Hatch Company, Loveland Colorado). Turbidity was analysed using a Jackson turbidity tube while total dissolved solids were analysed with a handheld meter, HM digital TDS-3 model. Turbidity and total dissolved solids were analysed at the study location. On thermotolerant coliform analysis, the forceps were flamed and sterilized before any use. The vacuum unit was wiped with alcohol and flamed before analysing each new sample. Once filtration was completed, the membrane was placed in a Petri dish and incubated at 44 $^{o}$C for 24 hours. After incubation, yellow, yellow-green, or yellow-brown colonies on the membrane were counted with the aid of a magnifying lens.

The MS 214 by Malawi Bureau of Standards (2013) was used to ascertain conformity of the water to drinking specifications. The study used standard procedure of Mzuzu University, Centre of Excellence in Water and Sanitation (procedure number 9 revision 0). The parameters tested were selected because the gadgets or instruments for testing were readily available. Additionally, they are the most common parameters used to determine the water quality for drinking.

#### *3.4.2 Factors affecting adoption of rooftop rainwater harvesting*

Data on factors affecting adoption of rooftop rainwater harvesting was collected using a household semi-structured questionnaire which was administered orally in the local language (Chichewa). An observational checklist included type of roof catchment, supporting collecting system, storage capacity and storage devices of the rooftop rainwater harvesting system. The face to face interviews helped the interviewee to understand and gain cooperation (Leedy & Ormrod, 2001). Pre-testing of the questionnaire was conducted in the City of Blantyre at Manyowe Township. Manyowe area has similar characteristics of the study area Nancholi. For example, Manyowe and Nancholi both are peri- urban and the settlement is non-linear. Pre-testing questionnaires were tested to a total of 20 households. The pretesting data was used to restructure and modify e the questionnaire so as to gather the appropriate data for the study. Questions on the questionnaire included those on, storage devices, storage capacity, roof catchment, household perception, access to information, water sources, distance to water source, access to information and household size.

### 3.5 Data management and statistical analysis

#### *3.5.1 The RRWH system among households*

The Chi-square test was used to determine the RRWH system among households. Chi-square test is a family test which is used when data is drawn from a population and sample size which is large enough (Boiboala et al., 2011). The following formula, therefore, was used:

$$X^2 = \sum_{i=1}^{f} \frac{(O_i - E_i)^2}{E_i}$$

#### *3.5.2 Rooftop rainwater quality for drinking and domestic use*

Descriptive statistics such as means, median, maximum, minimum and percentages were used to detect correlations between related variables. To illustrate the characteristics of the study, the descriptive statistics such as means, maximum, minimum and percentages were calculated using SPSS 16.0. The descriptive statistics helped the study to measure the central of tendency and dispersion (Marshall & Jonker, 2010).

#### *3.5.3 Factors that affecting the adoption of RRWHT*

There are many statistical models used to establish a relationship between the household characteristics and adoption of technology. The linear probability and non-linear model are more appropriated for the S shaped curve bounded with an interval of 0 and 1. Alemayohu (2013) reported that S-shaped curves satisfy the probability model especially those that are presented by the cumulative logistic function (logit) and cumulative normal distribution function (probit).

Hosmer and Lemshew (1989) state that a logistic regression has advantage over other models in the analysis of dichotomous outcome variables. The reasons for using logistic regression is due to its flexible, easily used function and it interpret the meaning itself. The logit model is simpler in estimation than the probit model. Therefore, a binary logistic regression model was used to determine factors affecting adoption of RRWHT.

Following Hosmer and Lemshew (1989), the logistic distribution function use defined as:

$Pi = \frac{1}{1+e^{-Z_1}}$ ……………………………………………………………………………………1

where $P_i$ is the probability of the $i^{th}$ households being adopters of RRWH and $Z_i$ is a function of m explanatory variable ($X_i$), and expressed as:

$Zi = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \text{----} + \beta_m X_m$ ……………………………………………………………………..2

Alemayohu (2013) states that $B_o$ is the intercept and $B_{i\ (1,2\ldots m)}$ are slope parameters in the model. The slope informs how the log-odds in favor of being adopter of the RRWH as independent variables change. Since the conditional distribution of the outcome variable follows a binomial distribution with a probability given by the conditional mean Pi, interpretation of the coefficient is understandable if the logistic model can be rewritten in terms of the odds and log of the odds. The odds is defined as the ratio of the probability that a household is adopter ($P_i$) to the probability that the household is not adopter (1- $P_i$). However,

$1\text{-}P = \frac{1}{1+e^{Z_1}}$ ………………………………………………………………………………… 3

Therefore,

$$\frac{P_1}{1-P_1} = \frac{1+e^{Z1}}{1+e^{-Z1}} = e^{Z1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

And

$$\frac{P1}{1-p} = \frac{1+e^{z1}}{1+e^{-z}} = e^{Bo+} \sum_{i=j}^{m} BiXi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Table 1 contains the summary of the methods and materials that were used during data collection. It also states the variables tested so as to achieve each objective.

**Table 1:** Summary of materials and methods.

| **Goal** | **Specific objective** | **Variables** | **Data collection** | **Data analysis** | **Statistical package** |
|---|---|---|---|---|---|
| To assess the system, rainwater quality for domestic use and factors affecting adoption of rooftop rainwater harvesting technology | To determine the system of RRWH | Roof catchment, supporting collecting system, storage capacity, and storage devices. | Questionnaire and Observation check list | Chi-square | SPSS 16.0 |
| | To analyse rainwater quality for drinking and domestic use | pH, total alkalinity, total chlorine, free chlorine, total hardness, turbidity, thermotolerant coliform | Laboratory test | Descriptive statistics (mean, maximum and median and minimum) | SPSS 16.0 |
| | To identify factors that affects adoption of RRWHT | Household size, household perception, water source, water source distance and access to information and household income. | Questionnaire | Binary logistic regression model | SPSS 16.0 |

# CHAPTER 4: RESULTS

This chapter outlines the study results based on the following sub topics: the RRWH system, water quality results from the harvested rainwater and factors affecting adoption of RRWHT.

## 4.1 The RRWH system among households

According to field observations, all households (100%, $n$ = 100) have catchments made of iron sheets. Very few (6%) use supporting collecting system as gutters while majority (94%) use collecting vessels. The households in the area use water storage vessels of varying capacity depending on availability. The results on storage capacity show that nearly half (43%) of RRWH adopters use kitchen utensils that have storage capacity of between 100 and 200 litres. Less common (18%) were drums and tanks that have storage capacity ranging from 500 to 1000 litres. Due to lack of storage facilities the harvested rainwater is not stored for more than 2 weeks. The Chi-square test was conducted in order to determine the system of RRWH among the household. The results (Table 2) indicate that there are no differences in roof catchment supporting collecting system, storage devices and storage capacity among households practicing RRWH.

**Table 2:** Determination of system designs of rooftop rainwater harvesting technology.

| **Variable** | **STD Error** | ***p* = value** |
|---|---|---|
| Roof catchment | 27.347 | 0.056 |
| Supporting collecting system | 0.288 | 0.000* |
| Storage devices | 0.394 | 0.000* |
| Storage capacity | 0.01 | 0.000* |

Confidence Interval= 95%

**Note**: * shows Significant different, STD: Standard.

### 4.2 Rooftop rainwater quality for drinking and domestic use

Results for levels of pH, total alkalinity, total chlorine, free chlorine, total hardness, total dissolved solids, turbidity, and thermotolerant coliform in the harvested rainwater are presented in figures below.

#### 4.2.1 *The pH*

The results (Figure 4) of pH levels shows that all samples (100%, *n*=100) were within the recommended range of MBS 2013 and WHO 2017. The harvested rainwater from roof have pH levels of 6 to 7ppm.

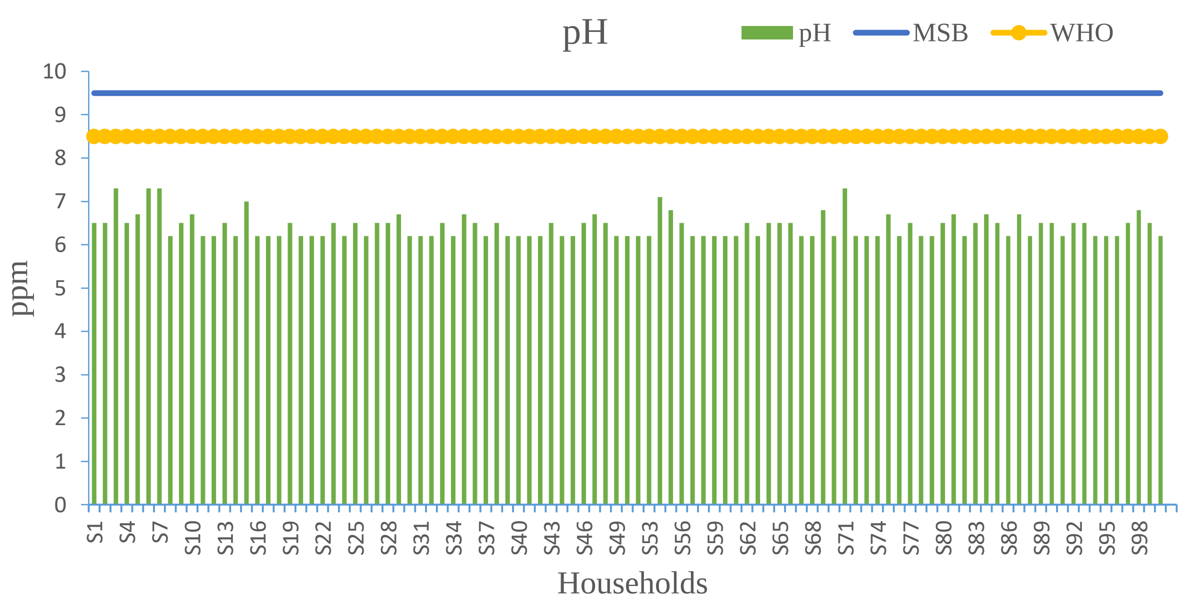


**Figure 4:** The pH levels.

### *4.2.3 Alkalinity*

The study results (Figure 5) on alkalinity indicate the values between 37 and 80 ppm. The majority (100%, *n*=100) of the samples were within the guidelines of WHO. For MBS there is no guidelines for alkalinity.

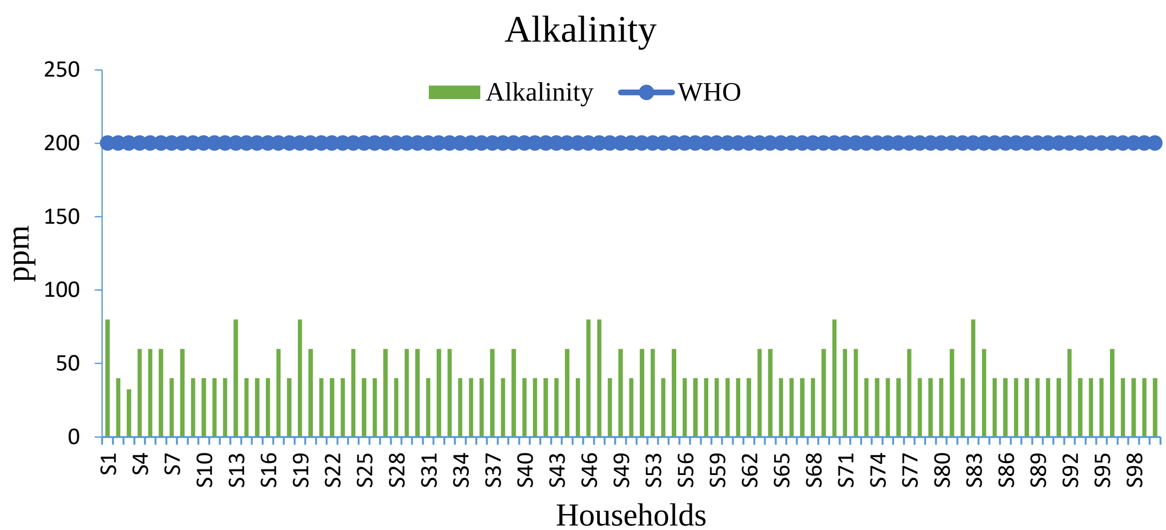


**Figure 5:** Alkalinity levels.

### *4.2.4 Total Hardness*

The study results (Figure 6) indicated that the level of total hardness in harvested rainwater were from 25 to 50 ppm. The results indicate that the values were within the specification provided by WHO 2017. While on MBS, there is no guidelines.

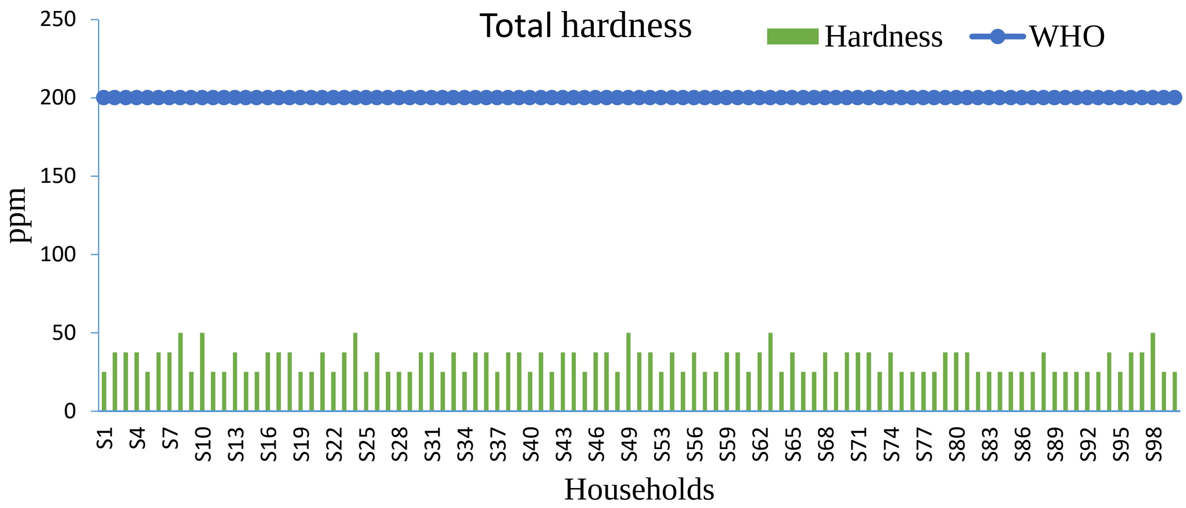


**Figure 6:** Total hardness levels.

#### *4.2.5 Free chlorine*

The study results (Figure 7) found that majority of (100%, *n*=100) of all rainwater samples did not show the present of free chlorine. The values were within the guidelines of both MSB and WHO.

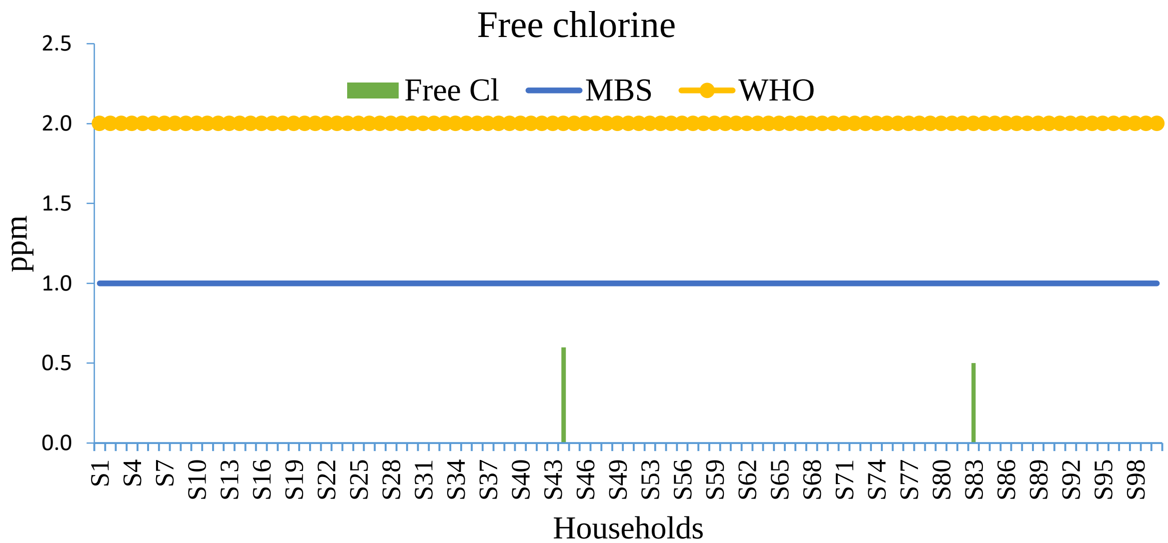


**Figure 7:** Free chlorine levels.

#### *4.2.6 Total chlorine*

The study results (Figure 8) found that nearly (100%, *n*=100) of all rainwater samples did not show the present of total chlorine. The values were within the guidelines of both MSB and WHO.

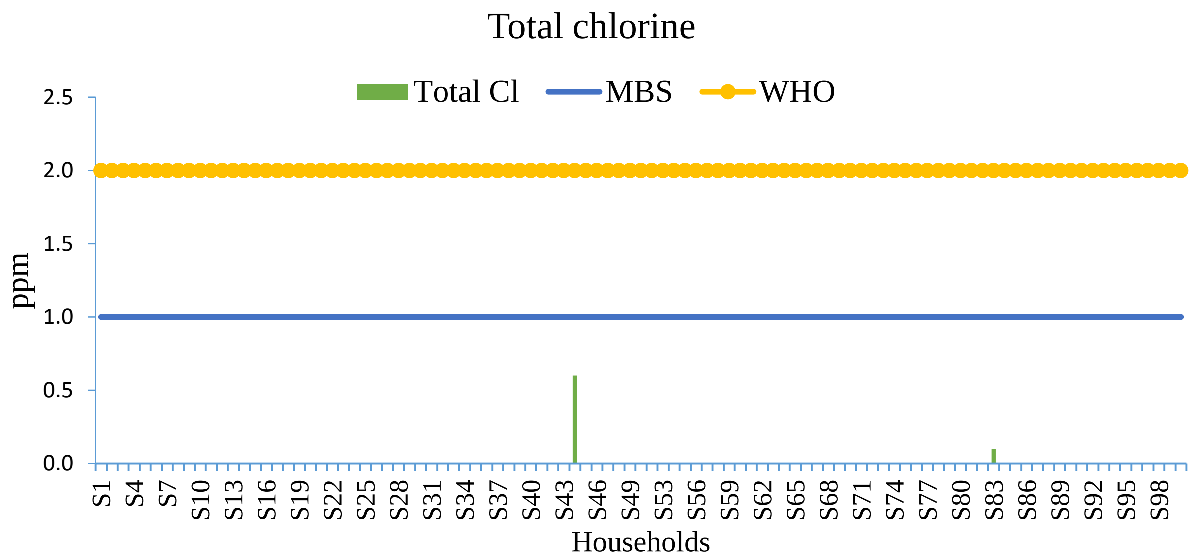


**Figure 8:** Total chlorine levels.

#### *4.2.7 Total dissolved solids*

The study results (Figure 9) found that the level of total dissolved solids did not exceed the guidelines of MBS and WHO. In all samples collected the values of total dissolved solids did not exceed 25ppm. All (100%, *n* =100) samples collected meet the requirements of drinking water.

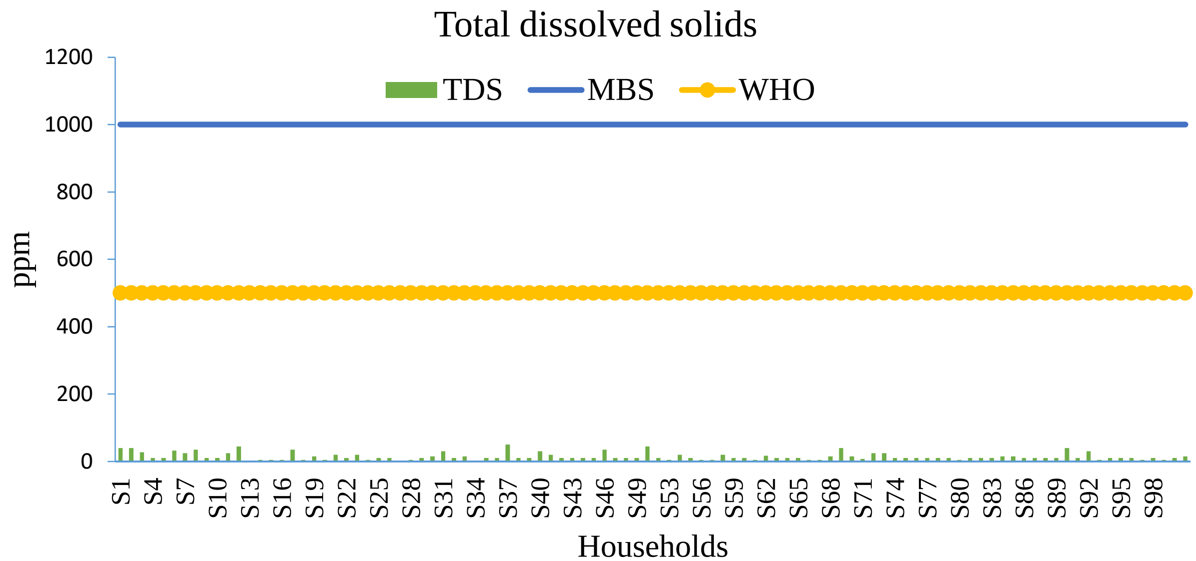


**Figure 9:** Total dissolved solids.

#### *4.2.8 Turbidity*

The rainwater quality analysis results (Figure 10) shows that level of turbidity ranged from 5 to 25JTU. The majority (71%, *n* =100) of the samples were above the requirement of MBS and WHO.

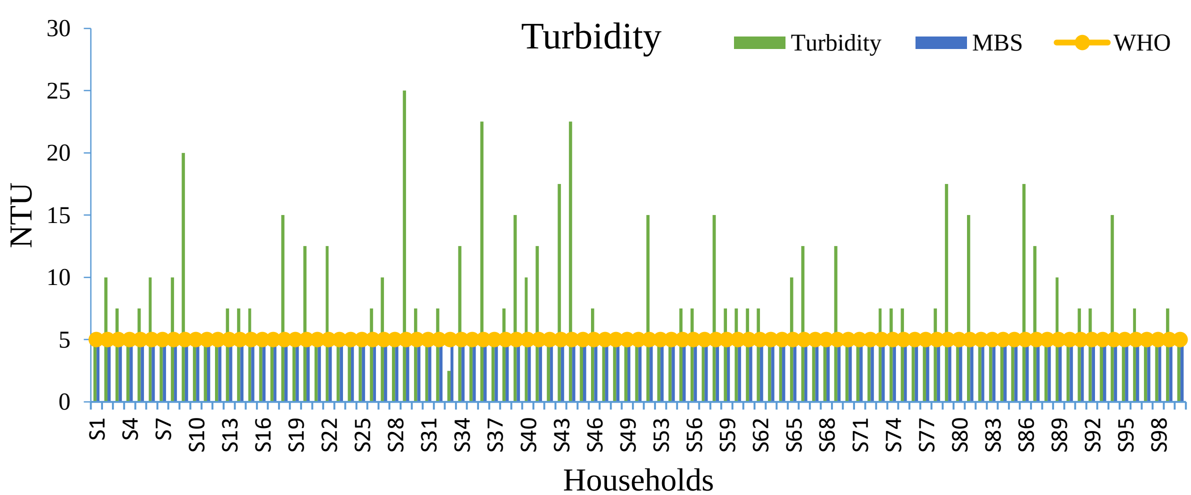


**Figure 10:** Turbidity levels.

*4.2.9 Thermotolerant coliform*

The results (Figure 11) indicated that almost (97%, *n*=100) all samples contains E. coli. Further, the study shows that the harvested rainwater did not meet the requirements of MBS and WHO. The values exceeded the requirements of MBS and WHO.

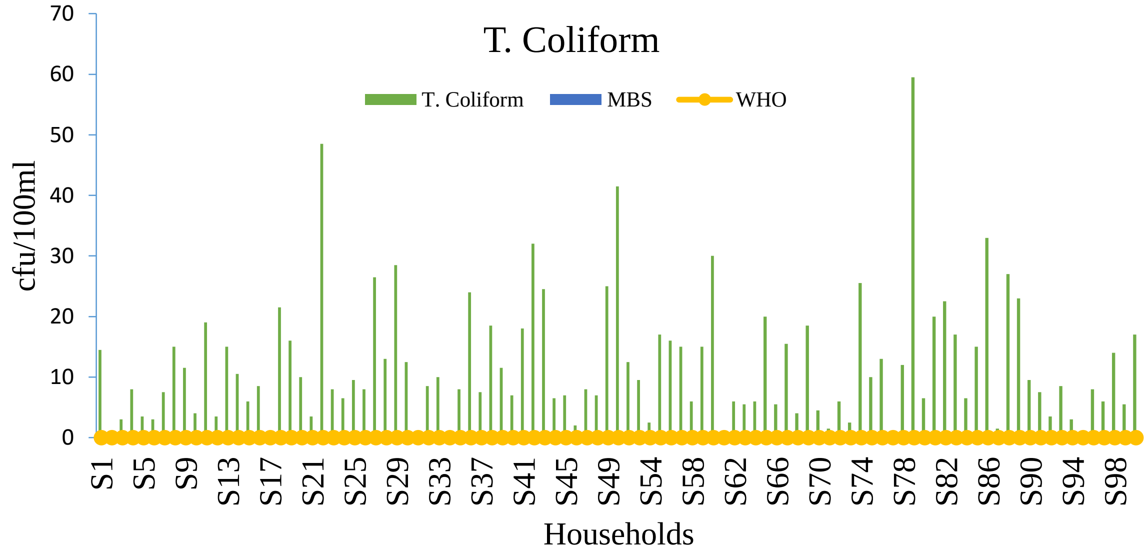


**Figure 11:** Thermotolerant coliform levels.

*4.2.1 Distribution of water quality parameters*

The pH results ranged from 6.2 to 7.8. The results for total alkalinity ranged from 40ppm to 80 ppm while total hardness is distributed across the geographic area in the range of 25 ppm to 41ppm.The study found that total dissolved solids ranged from 0 to 50 ppm. The level of turbidity in water samples was between 5NTU and 25 NTU. Finally, thermotolerant coliform count ranged from 0 to above 50 cfu/100 ml. The distribution of each parameter among household are presented in Appendix H.

### *4.2.2 Suitability of harvested rainwater for drinking and domestic use*

The results (Table 3) illustrate the average values of harvested rainwater parameters for the two roof conditions (from rusted and non-rusted roofs). The results were compared against the recommended standards for drinking water according to the Malawi Bureau of Standards (2013). For pH, free chlorine, total chlorine and total dissolved solids, all (100%, $n$ = 100) of the rainwater samples met the Malawi Bureau of Standards requirements.

**Table 3:** Suitability of rainwater for drinking.

| Parameter | Minimum | Maximum | Median | Mean |
|---|---|---|---|---|
| pH | 6 | 7 | 7 | 6 |
| Alkalinity (ppm) | 37 | 80 | 40 | 49 |
| Hardness (ppm) | 25 | 50 | 32 | 32 |
| Free Cl (ppm) | 0 | 1 | 0 | 0 |
| Total Cl (ppm) | 0 | 0 | 0 | 0 |
| TDS (ppm) | 0 | 45 | 10 | 15 |
| Turbidity (JTU) | 4 | 23 | 7 | 9 |
| Thermo tolerant coliform(cu/100ml) | 0 | 60 | 10 | 12 |

## 4.3 Factors that affect adoption of RRWH

The overall percentage of correct predictions of factors affecting adoption of rooftop rainwater harvesting technology was about 65 %. The $p$-value 0.001 uses the Hosmer and Lemeshow Goodness-of-Fit Test, which is computed from the Chi-square distribution with 1 degrees of freedom (d.f), confirms that the model estimates very well fit the data.

The corresponding odds ratio (Column, Exp (β)), in Table 4 gives the exponential of expected value of β raised to the value of the logistic regression coefficient, which is the predicted change in odds for a unit increase in the corresponding explanatory variable. Three explanatory variables in the model were statistically significant at 5% level in explaining the RRWHT adoption behavior at Nancholi expressed in terms of the variables used in this case, and the logistic regression equation.

**Table 4:** Factors affecting adoption of rooftop rainwater harvesting technology.

| **Variable** | **B** | **S.E.** | **Wald** | **df** | **Sig.** | **Exp(β)** | **95.0% C.I.for EXP(B)** | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Household size | 0.808 | 0.429 | 3.55 | 1 | 0.006 | 2.244 | 0.968 | 5.2 |
| Household perception | -0.93 | 0.401 | 5.43 | 1 | 0.002 | 0.393 | 0.179 | 0.862 |
| Access to information | 0.002 | 0.299 | 0 | 1 | 0.995 | 1.002 | 0.557 | 1.801 |
| Water source distance | 0.58 | 0.507 | 1.31 | 1 | 0.253 | 1.786 | 0.661 | 4.825 |
| Water source | 0.011 | 0.306 | 0 | 1 | 0.972 | 1.011 | 0.554 | 1.843 |
| Household income | -0.26 | 0.209 | 1.57 | 1 | 0.002 | 0.769 | | |
| Constant | 0.957 | 1.232 | 0.6 | 1 | 0.437 | 2.605 | | |

**Note**: B=Slope, S.E. Standard error, df= degree of freedom, Sig= Significant different, CI= Confident Interval, Exp(β)= Odds ratio.

The results indicate that there were differences in the RRWH system among households. The rainwater did not contain free and total chlorine. The parameters like pH, total alkalinity, TDS and hardness met the MBS requirements. However, turbidity and thermotolerant coliform did not meet the requirements. The harvested rainwater contained microbes, hencenot fit for drinking. The study found that household size, household perception and household income are the factors affecting adoption of rooftop rainwater harvesting technology.

# CHAPTER 5: DISCUSSION

The chapter discusses the results of the RRWH system in the study area, suitability of rainwater quality for drinking as well as domestic use and factors affecting adoption of the RRWH technologies.

## 5.1 The RRWH system among households

This section contains summary of the discussions of the first objective which is to investigate the RRWH system. The discussion will be based on the components of the RRWH which are roof catchment, supporting collecting vessel, storage devices and storage capacity.

### *5.1.1 Roof catchment*

Roof catchment is an ideal for the RRWH since it receives rainfall and provides water to the system (Biwas -& Mandal, 2014). Many studies conducted research in order to determine the type of roof catchments used for water collection. For example, Saleh et al., (2017) and Chaplin and Legge (2019) found that the RRWH is composed of roof catchment area made of metal and concrete. Tobin et al., (2013) found that, at Edo state in Nigeria roof catchments are made of aluminium and iron sheets. Contrary, to other study findings this study found that there are no significant differences in roof catchment. All the households practicing RRWH have roof catchments made of iron sheets. The reason attributed to the study findings is that iron sheets are cheap where by each household in peri-urban afford to buy. Additionally, iron sheets are available in many shops and in different sizes as well as different quality.

### *5.1.2 Supporting collecting system*

Biwas and Mandal (2014) state that there are differences in supporting collecting systems used among households. Tobin et al., (2013) found that there are differences in supporting collecting systems used, for example, other households use gutters made of PVC while others use gutters made of metals. This study found that there are differences on supporting collecting systems used among households. Some households use gutters made of plastics, others made of metals and other households use collecting vessels. The research noted that shapes of the gutters are different; they range from V-shape, semi-circular to rectangular**.** This study suggests that the differences are related to the household income. On the one hand, the households that have the RRWH system mounted to the houses use down pipes. On the other hand, households that has the system not mounted to the house use collecting vessels. The collecting vessels are used to collect rainwater and when full of water they are transported inside the house where large storage are kept manually. The process continues until all the storage devices are full of water.

### *5.1.3 Storage devices*

Several studies were conducted to assess the type of storage devices used for the RRWH. Kariuki (2011) found that households use any available storage devices like kitchen utensils, drums and tanks. Mohite and Lole (2014) found that either plastic or concrete tanks are used to store harvested rainwater. In relation with other findings, the study found that households use any type of storage devices which include kitchen utensils, drums and tanks. The study suggests that households use different kinds of storage devices because they are cheap and readily available e.g. plastic devices. Additionally, inadequate financial resources to purchase large storage vessels and poor security for the mounted facilities of RRWH systems prevent most households from using large storage devices and instead prefer smaller capacity to enable them to be kept inside the house.

#### ***5.1.4 Storage capacity***

The study noted that there are differences on the storage capacity used to store harvested rainwater among households. The capacity of the storage vessels was small that they cannot accommodate enough water required by the households for many days. All the storage vessels used by households in the study area have storage capacity of between 100 litres and 1500 litres which belong to small capacity of less than 2000 litres (Shittu et al., 2015). The reason why households use different kinds of storage devices that have capacity of less than 2000 litres could be inadequate finances. Households with low income are unable to purchase storage devices that has high capacity. In agreement with the study findings, Kariuki (2011) found that households use any type of storage devices for example kitchen utensils, drums and tanks that have different capacity.

### 5.2 Rainwater quality for drinking and domestic purposes

This section contains summary of the discussions of the second objective which is to evaluate the water quality of rooftop harvested water for drinking and domestic use. The discussion will be based on the following water quality parameters: pH, total alkalinity, chlorine, total hardness, total dissolved solids, turbidity and thermotolerant coliform.

#### ***5.2.1*** **The *pH***

Several studies on determining the levels of pH of harvested rainwater from rooftops have been conducted. Daoud et al. (2015) found that the pH values of roof harvested rainwater in the West Bank of Palestinian had an average range of 4.5 to 6.5. Similar to other findings, Fadilu et al.

(2015) found that pH values of harvested rainwater from roof ranges from 4.5 to 6.9. The study findings indicate that the pH values ranged from 6.2 to 7.8 which is acidic to alkaline.

The results meet the specification of MBS. The slightly acidic to alkaline rainwater noted was attributed to contamination of the water with dirty and debris. The bacteria contained in dirty and debris are released into rainwater hence the acidic or alkaline level of pH. The level of bacteria released in water determine rainwater to be acidic or alkaline.

### *5.2.2 Total alkalinity*

Many studies have analysed total alkalinity of the harvested rainwater. For example, Chukwuma et al. (2014) found that the level of total alkalinity in rooftop rainwater is very low with the values ranges from 8 mg/l to 20 mg/l. Similarly, Iyidiobu and Omale (2015) found that the level of total alkalinity in rainwater harvested from roof ranged from 22 mg/l to 250 mg/l. This study found the level of total alkalinity ranged from 40 ppm to 80 ppm which is within the requirement of MBS. The result of total alkalinity levels is attributed to the less chemical reactions that take place between chemicals dissolved in rainwater and chemicals present in the RRWH system.

### *5.2.3 Total hardness*

Hardness is the total concentration of $Ca^{2+,}$ $Mg^{2+}$ and other ions present in water. The results on total hardness in this study ranged from 25 ppm to 50 ppm which represent soft water. The results were within the requirement of MBS. This means that the concentration of calcium and magnesium in rooftop rainwater are minimal. The low levels of calcium and magnesium in rooftop rainwater is attributed to the fact that rainwater do not pass through the ground nor rocks where calcium and magnesium are dissolved. The results are consistent with the results of

Owusu-Boateng and Gadogbe (2015) who found that the level of total hardness in harvested rainwater is low.

### *5.2.4 Chlorine*

Rainwater is tasteless and do not contain any chemical but gets contaminated with chemicals when the atmosphere is polluted with chemicals. The rainwater also gets contaminated with the chemicals that are accumulated in the RRWH system (Goyal, 2014). In another study, chlorine as a parameter exceeded the drinking standards of WHO (Payus & Meng 2015). In this study, the results indicate that the harvested rainwater does not contain either free or total chlorine. The possible explanation for the absence of (free and total) chlorine could be that, the atmosphere of the study area is not polluted with a chemical which leads to the presence of chlorine. Therefore, the harvested rainwater does not contain chlorine. Additionally, the RRWH system did not contain any chlorine.

### *5.2.5 Total dissolved solids*

The study conducted by Alile (2015) found low total dissolved solids concentrations as compared to the recommended guidelines for drinking water set by WHO. That study explains that high total dissolved solids indicate the presence of large amounts of ions such as nitrate, lead, copper, etc. which could be above the recommended standards. In another study done by Islam (2016), it was found that the range of total dissolved solids is 9.44 to 335.00 mg/l. This study found that the total dissolved solids of the rainwater were within the allowable limit of the Malawi Bureau of Standards (0 ppm to 50 ppm). The level of total dissolved solids is attributed to the fact that rainwater contains little inorganic and organic matter which contain cations such as calcium, magnesium and potassium and anions such as nitrate and chloride sulphate. Due to the small quantities of cations and anions, after chemical reaction low quantities of chemicals (magnesium and potassium) are dissolved in the water and hence the low values of total dissolved solids.

### *5.2.6 Turbidity*

The turbidity in water is increased when rainwater comes in contact and be contaminated with roof catchments which may contain a layer of soil particles, organic matter or biological particles (Owusu-Boateng & Gadogbe 2015). The results reveal that the turbidity levels of rooftop rainwater are more than 5 NTU. The results meant that the quality of rooftop rainwater was affected by debris which are accumulated in the RRWH system. This was attributed to the fact that most of the ground in the study area is bear with little or no trees or vegetation that bind the soil particles together. As a result, the soil surface experiences wind blowing which collect and deposits dust on roof catchments.

### *5.2.7 Thermotolerant coliforms*

Several studies analyse the quality of harvested rainwater. For example, Dauod (2015) and Hamilton et al. (2017) found that rainwater harvested from roofs are contaminated with E. coli. These studies state that the contamination of rainwater is attributed to the presence of birds, rodents, lizard faecal matter. Results show that the rooftop rainwater is contaminated with faecal coliform (thermotolerant coliform). The presence of thermotolerant coliform in harvested rainwater from rooftop is the result of the catchment location where the RRWH is practiced. The presence of animal droppings like birds and lizards in the RRWH system could lead to presence of thermotolerant coliform.

### *5.2.8 Rainwater quality for drinking and domestic purposes in relation to MBS*

The study results indicate that, pH, free chlorine, total chlorine and total dissolved solids complied with the requirements of the MS 214 Malawi Bureau of Standards (MBS) (2013). The turbidity, and thermotolerant coliform did not meet the minimum requirements of MBS. Therefore, the study concludes that the harvested rainwater can be used for domestic use so long as treatment e.g. use of water guard or boiling is applied to ensure the use of clean water. Contrary to these study findings, Payus and Meng (2015) in Malaysia indicate that the quality of harvested rainwater meets the requirements of the WHO and the Malaysian standards, where the pH, turbidity, total dissolved solids were within acceptable limits. Poor hygiene practices of the households using the system of water harvesting was a reason *E. coli* was found to exceed the standards in this study area of Blantyre. Despite these shortcomings, this study maintains that the rainwater harvested is suitable for drinking once water treatment (use of water guard and boiling) is applied. Therefore, the RRWHT can be considered as a potential alternative water source. All the harvested water in the study area is meant for drinking and domestic use and no revenue is collected because the households do not have adequate storage facilities to store water for sale.

### *5.2.9 Rooftop rainwater treatment*

In the study area rooftop rainwater is utilised without treatment. The reason for using untreated rainwater is that households believe that harvested rainwater from roof is safe for drinking and domestic use. Yet, to make rooftop rainwater safe for drinking and domestic use, rainwater can be treated either by using water guard or boiling. Sieving the harvested rainwater is another method of handling turbidity. In their studies Payus and Meng (2015), Radaideh et al. (2009) and Achadu et al. (2013) agree that rooftop rainwater is not safe for direct drinking and domestic use. Therefore, the harvested rainwater can be treated with water guard and boiling.

## 5.3 Factors that affects adoption of RRWHT

This section describes the result of objective number three, and the discussions will be based on the following: household size, household perception, water source, distance to water source, access to information and household income.

### *5.3.1 Household size*

The study results reveal that the size of household is related to the adoption of RRWHT. In a related study household size has shown significant positive relationship with adoption of RRWHT (Staddon, 2018). Commenting on the same, Mekonnen (2017) and Karidjo et al. (2018) state that there is a relationship between household size and adoption of RRWHT. Households that have more members have higher chances of adopting RRWHT than households with fewer members. In agreement with other study findings, this study found that households with more members and more little children are more likely to adopt the technology than smaller sized and households with adult members only. This is attributed to the fact that there is high water consumption in households with more members and in households with little children.

### *5.3.2 Water source*

Commenting on the relationship between water source and technology adoption, Shalamzari et al. (2016) report a positive relationship that exists between water source and adoption of RRWHT. The study explains that lack of access to water sources acts as a facilitator to the process of adopting water technologies. Contrary to other findings, this study found no relationship between water source and the adoption of the technology. The households that had and did not have piped water to their homes adopted RRWHT. So, this study argues that there is no relationship between water source and technology adoption.

This is attributed to the advantages of rainwater to the households. For example, use of rainwater contribute to the increase of household income by reducing water bills, it promotes household sanitation whereby household members take bath, wash their clothes, clean plates and houses. It can still be seen that the study does agree with the findings of Shalamzari et al. (2016), in that piped water in the study area provided only very limited access to water due to the price and the shortages**.**

### *5.3.3 Distance to water source*

There are variations in study findings on the effect of distance to water source and RRWH adoption. For example, Chuchid et al. (2017) suggest that distance has no influence on technology adoption, whether there were short or long distances households still adopted the technology. Contrary to the other finding Murgor et al. (2013) reveal that distance to water source is related to the adoption of technology of RRWH. This study found no significant relationship between distance to water source and technology adoption. This suggests that both nearby and distant water sources are unreliable. The other reason could be other water sources are expensive in terms of water bills as well as installation, hence the adoption.

### *5.3.4 Access to information*

Baiyegunhi (2015) states that a household's technology adoption is related to access to information. This collaborates with the findings of Ahamed et al. (2013) who found a positive relationship between access to information and the adoption of RRWH techniques. In agreement with the two findings, Shange (2015) concludes that access to information results in the adoption of the technology. In contradiction with other study findings, this study found an insignificant relationship between access to information of RRWH and technology adoption. The results mean that there is no relationship between access to information and adoption of RRWHT.

The possible reason could be that households copied from neighbours without asking for information. Apart from having access to information there are many ways of understanding the innovation, an example could be, copying from other households. The results can also be attributed to the fact that they inherited from their parents who used the system since long time ago hence, the adoption.

#### *5.3.5 Household perception*

Perception of RRWH is related to rainwater quality, water availability and access to drinking water (Selabe & Minyoli, 2018). The study found that there is a relationship between household perception and adoption of RRWHT. The reason could be households consider rainwater to be clean and safe for drinking and does not causes water related disease like cholera that is why they have adopted the technology of RRWH. In reference to the findings of the study, Baiyegunhil, (2015) found that household perception is positively related to adoption of RRWHT. The households that have positive perception are the ones that adopted the technology. Contrary to the study findings Ward et al. (2008) found that household perception is not related to the adoption of RRWHT. The reason is that households believe that rainwater has poor quality. It is associated with water related diseases hence not recommended for domestic use.

#### *5.3.6 Household income*

The position of household income is important as far as adoption of rainwater harvesting technology is concerned. The empirical results show that the effect of household income on adoption of rooftop rainwater harvesting technology is positive. This means that as monthly income level of the household increases, from any income sources, the degree to adopt rooftop rainwater harvesting technology increases proportionally.

Alemayohu (2013) in Nigeria, reports that money increases the investment power of the households. This is in line with the hypothesis which states that ‘income and demanded quantity are positively related in the case of normal goods’. The minimal effect of income implies that, other things remaining the same, as income of the household increases the decision to adopt technology increases. Gebregziabher et al. (2013) also support by stating that effect of capital on technology adoption is positive. Households that have an occupation of some kind are likely to adopt the technology because they have income to purchase the material required for rooftop rainwater harvesting technology.

The study concludes that there are significant differences in the system of RRWH in the study area. Some households have the system attached to the house where down pipes are used to transport water to the storage tank.  Others have the system that is not mounted to the house they use collecting vessels to collect the harvested rainwater. On suitability for drinking and domestic use, the study results show that, pH, free chlorine, total chlorine, hardness and total dissolved solids did not meet the requirements of MBS. On the one hand, turbidity and thermotolerant coliform did not meet the requirements of MBS. Finally, the results indicate that household size, household perception and household income are factors that influence adoption of RRWHT.

# CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion and recommendations on the assessment of factors affecting adoption of rooftop rainwater harvesting technology and water quality for domestic use. The proposed areas of further studies are provided.

## 6.1 Conclusion

The study found that, on the one hand, there are no significant differences in roof catchment of RRWH system among households hence accepting hypothesis. On the other hand, the results indicate that there are significant differences in supporting collecting system, storage devices and storage capacity hence rejecting the hypothesis. On water quality, there are no significant differences between rainwater quality levels of the following parameters: pH, total alkalinity, total hardness, free and total chlorine, and total dissolved solids and the water quality standards stipulated by the Malawi Bureau of Standards (2013) hence, accepting the hypothesis. On the other side, there are significant differences between rainwater quality levels of turbidity and thermotolerant coliform and the water quality standards stipulated by the Malawi Bureau of Standards (2013) there by rejecting the hypothesis. The study also found that there are no significant differences between rainwater quality harvested from rusted roofs and non-rusted roofs thereby rejecting that hypothesis. On factors that affect adoption of RRWHT, the study found that household size and traditional culture have a significant influence on the probability of adopting RRWH technologies, thereby rejecting those hypotheses. The study however found that distance to water source, water source and access to information have no relationship with the adoption of RRWH technologies, thereby accepting those hypotheses.

## 6.2 Recommendations

Based on the study findings, the following recommendations are made:

**a.** The RRWH system should be composed of roof catchment, conveyance system and storage devices.

b. Harvested rainwater from the roof needs to be treated before drinking to make it safe and clean.

c. Household size and household perception and household income should be considered when developing adoption strategies of RRWH.

## 6.3 Areas of further study

a) Assess the influence of climate change on RRWH and adoption strategies by different groups of households to water shortages.

b) Determine the total roof catchment area of households at Nancholi and estimate the total amount of rainwater harvested from rooftop.

c) Investigate healthy impacts and effective water treatment methods on the harvested rainwater from rooftops at Nancholi in Blantyre.

d) Determine the quality of rainwater harvested from roof catchments made of heavy metals and painted with different paints.

e) Determine the quality of rainwater harvested (parameters to include iron and zinc) and stored in different storage devices.

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## Appendix A: Ethical Clearance

NATIONAL COMMISSION FOR SCIENCE & TECHNOLOGY

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**REF.NO.NCST/RTT/2/6** **14th December, 2017**

Chrissie Msulira Banda
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Centre of Excellence in Water and Sanitation
P/Bag 1
**LUWINGA**

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Dear C Msulira Banda,

**Approval of Protocol P.12/17/236: Assessment of factors affecting adoption of roof rainwater harvesting technology and water quality for domestic use**

Having reviewed your submission, the National Committee on Research Ethics in the Social Sciences and Humanities (NCRSH) hereby grants you a research ethics approval and regulatory permit to conduct the above referred study in Malawi. This approval is valid for **one year** from the date indicated above.

Should the study go beyond one year, you will be required to submit an application for annual review and continuation on a form available at the committee secretariat before the expiry date of this approval.

Wishing you a successful implementation of the study and the committee awaits a copy of the written technical report.

Yours Sincerely,

Mike G Kachedwa
**CHIEF RESEARCH SERVICES OFFICER & HEAD OF NCRSH SECRETARIAT**
**For: CHAIRMAN OF NCRSH**

## Appendix B: Household Questionnaire

**Introduction**

The aim of this study is to assess factors affecting the adoption of roof rainwater harvesting technology and water quality for domestic use. The study will be achieved by investigating factors affecting adoption of roof rainwater harvesting and lastly to analyse harvested rainwater quality.

| Interviewee | Location of the interview | Date | Serial No |
|---|---|---|---|
| | | | |

**A. Demographic information**

Q1. Household name______________________________________

Q2. Household size ____________________________ (number)

**B. Available water sources**

Q3. Which one is your main source of water supply do you use?

1 Piped water 2 rainwater harvesting 3 Borehole 4.River

5 Others specify

**C. Non roof rainwater harvesting technology adopters**

Q4. Why are you not harvesting rainwater from roof for domestic use?

Q5. Do you have any interest in adopting RRWHT? If no explain the reasons

Q6. In your opinion do you think by adopting RRWHT will improve your way of living?

**D. Rooftop rainwater harvesting adopters**

Q7. What type of storage devices do you use for roof water harvesting?

1 Drum 3 Tank

2 Kitchen buckets 4 others, specify ___________

Q8. What are the reasons for practicing harvested rainwater technology?

1 To obtain water 2 To reduce runoff 3 Others specify

Q9. What is the main purpose of the harvested rainwater?

Q10. Rank the following use of harvested rainwater at home based?

| **Rainwater use at home** | **Which activity use more water** | **Which activity is most important** |
|---|---|---|
| Cooking & drinking | | |
| Washing clothes | | |
| Bathing | | |
| Cleaning the house & dishes | | |

Q11. Is the harvested rainwater accepted by your culture?

1Yes 2 No

Q12. If No what are the reasons?

Q13. If yes what are the reasons?

Q14. How does the adoption of RRWH changed your life compared when you had not adopted?

Q15. Are you able collecting all water from your roof?

1 Yes 2 No

Q16. If No what are limitations?

Q17. If yes how do you achieve?

Q18. What are the benefits does your house get from the roof rainwater harvesting?

Q18. How would you describe the level of information available of roof rainwater harvesting technology?

1 Adequate information 2 inadequate information 3No information

**E. Gender and water harvesting**

Q20. Who makes decision on the adoption of rainwater harvesting system?

1. Wife 2. Husband

Q21. Why is the decision decided by the person mentioned above?

Q22. Do men and women have equal access to information when it comes to roof rainwater harvesting technology?

Q23. In your view what should be done to improve adoption of roof rainwater harvesting by many households?

Q24. In your view what do you think should be done to increase adoption of roof rainwater harvesting by households in the city?

Q 25 Described when and how maintenance of RRWHS is carried out?

Q26. Described when and how maintenance of RRWHS is carried out?

Q27. Does you involve an engineer to install and construction of RRWH?

Q28. Do you have any questions?

**B. Observational checklist**

Q1. What type of roof material is the house built from? (Observe and record)

1 Tiles 2 Grass 3 Iron sheet 4 others specify

Measure using a tape measure

Q2. Observe the design and operation of RRWHS

Q3. What is the distance of the main water sources from the house to the water sources?

Q4. If RWH is being practiced, what is the storage type and capacity of the device in liters?

1 100 liters 2 500 liters 1000 liters

4 5000 liters. 5 Others specify

## Appendix C: Informed Consent Form for Research


**MZUZU UNIVERSITY**

**CENTRE OF EXCELLENCE IN WATER AND SANITATION**

**Private Bag 201**
**Luwinga**
**Mzuzu 2**
**Malawi.**
**Tel:** (265) 01 320722,
(265) 01 320575, or
(265) 01 930 796
Fax:(265) 01 320 505

Centre of Excellence in Water and Sanitation

Mzuzu University

P/Bag 201, Mzuzu 2, Malawi


### Informed Consent Form for Research

**Introduction**

I am Chrissie M. Banda from Centre of Excellence in Water and Sanitation, Mzuzu University. We are doing research on **Assessment of factors affecting adoption of roof rainwater harvesting technology and water quality for domestic use.** This consent form may have words that you do not understand. Please you are free to ask any question as we go through I will take time to explain where you do not understand.

**Purpose of the research**

This research aims to assess factors affecting adoption of roof rainwater harvesting technology and water quality for domestic use.

**Type of Research Intervention**

This research has selected your household to be interviewed on your general roof rainwater harvesting technology knowledge and practices.

**Participant Selection**

You are selected to take part in this research**.**

**Voluntary Participation**

You are entirely voluntary to participate in this research. You are free to participate or not. Nothing will changed if you decide not to participate. You are allowed to any question and proceed to next question.

**Duration**

The duration of this research will take over 12 months in total.

**Risks**

If you feel the question is too personal or uncomfortable you are free not to answer such question.

**Reimbursements**

In this research you are not provided with any incentive.

**Sharing the Results**

The results gained from this study will be shared with you and entire community before to the public. After that the results will be published for others to appreciate.

**Who to Contact**

If you have questions, you are free to ask. If you like to ask the questions later, you can contact: Dr. Rochelle Holm, Mzuzu University, Centre of Excellence in Water and Sanitation, P/Bag 201, Mzuzu 2, Cell: +265992159079 or +265882725730.

The proposal of this study has been reviewed and approved by NCST which is a committee that ensure that research participants are secured from danger. For more information on 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?

**Part II: Certificate of Consent**

I have been called to participate in research about assessment of factors affecting adoption of roof rainwater harvesting technology and water quality for domestic use.

I read the information, or the information was read to me. I was given opportunity to ask questions and was answered to my satisfaction. I consent voluntarily to be a participant in this study

Print Name of Participant___________________

Signature of Participant ___________________

Date ____________________________

Day/month/year

If illiterate [1]

I have observed the accurate reading of the consent form to the participant, and the participant was given opportunity to ask any questions. I confirm that the participant has given consent freely.

Print name of witness_____________ Thumb print of participant

Signature of witness ______________

Date __________________________

Day/month/year

Statement by the researcher/person taking consent

I have read the information to the participating participant accurately. To the best of my knowledge the participant understands the research study. I confirm the participant was given an opportunity to ask questions related to the study. To the best of my knowledge all the questions asked by the participant have been answered correctly. I confirm that the participants were not forced into giving consent but it has been given freely and voluntarily.

**Signature of Researcher /person taking the consent____________________________**

**Date _____________________________**

Day/month/year

[1] A literate witness must sign (if possible, this person should be selected by the participant and should have no connection to the research team). Participants who are illiterate should include their thumb print as well.

## Appendix D: List of random numbers for RRWH adopters

| Serial No | Household no | Name | Southern | Eastings | HH (RWH) | Random |
|---|---|---|---|---|---|---|
| 1 | 115 | Mkunda | -15.82616 | 34.98069 | 1 | 1 |
| 2 | 132 | | -15.82593 | 34.97965 | 2 | 1 |
| 3 | 47 | Galazo | -15.82919 | 34.9709 | 3 | 3 |
| 4 | 42 | Msusa | -15.82864 | 34.98034 | 1 | 4 |
| 5 | 120 | Mbuya | -15.82662 | 34.98111 | 1 | 4 |
| 6 | 109 | Banda | -15.82711 | 34.98073 | 2 | 6 |
| 7 | 76 | Tembo | -15.82592 | 34.98247 | 1 | 7 |
| 8 | 144 | | -15.82524 | 34.98047 | 1 | 7 |
| 9 | 27 | Kagwa | -15.82765 | 34.98159 | 2 | 8 |
| 10 | 29 | Micheus | -15.82948 | 34.98059 | 2 | 8 |
| 11 | 125 | | -15.82769 | 34.97966 | 2 | 8 |
| 12 | 189 | | -15.819012 | 34.98389 | 1 | 10 |
| 13 | 130 | | -15.8228 | 34.97969 | 2 | 11 |
| 14 | 38 | Tamani | -15.829 | 34.98003 | 1 | 12 |
| 15 | 40 | Micheus 1 | -15.82886 | 34.98028 | 1 | 12 |
| 16 | 164 | | -15.821919 | 34.983116 | 3 | 14 |
| 17 | 127 | Ostein | -15.82747 | 34.97955 | 1 | 15 |
| 18 | 52 | Mpakula 1 | -15.82797 | 34.98017 | 1 | 16 |
| 19 | 135 | | -15.82598 | 34.9804 | 1 | 18 |
| 20 | 17 | | -15.82811 | 34.98087 | 2 | 19 |
| 21 | 138 | | -15.82607 | 34.98403 | 2 | 19 |
| 22 | 89 | | -15.82564 | 34.9837 | 1 | 20 |
| 23 | 195 | | -15.820548 | 34.979976 | 2 | 20 |
| 24 | 185 | | -15.819134 | 34.983462 | 5 | 21 |
| 25 | 63 | Chiimire | -15.82895 | 34.97941 | 1 | 23 |
| 26 | 167 | | -15.822292 | 34.982765 | 2 | 23 |
| 27 | 186 | | -15.819027 | 34.983293 | 1 | 23 |
| 28 | 3 | Yohane | -15.82837 | 34.98183 | 7 | 25 |
| 29 | 30 | Chiwamba | -15.82896 | 34.9811 | 2 | 25 |
| 30 | 139 | | -15.82593 | 34.98113 | 1 | 25 |
| 31 | 165 | | -15.82203 | 34.982893 | 3 | 25 |
| 32 | 221 | | -15.823536 | 34.98204 | 2 | 25 |
| 33 | 15 | Chilanga | -15.82826 | 34.98381 | 1 | 26 |
| 34 | 37 | Khungwa | -15.82891 | 34.98037 | 1 | 26 |
| 35 | 91 | Mwenjemeka | -15.82624 | 34.98287 | 2 | 26 |
| 36 | 111 | Kanada | -15.82712 | 34.98056 | 1 | 26 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 37 | 192 | | -15.819144 | 34.984293 | 1 | 26 |
| 38 | 57 | Govati 2 | -15.82884 | 34.97887 | 1 | 28 |
| 39 | 79 | | -15.82633 | 34.98306 | 3 | 28 |
| 40 | 94 | Salu 2 | -15.82625 | 34.98347 | 2 | 28 |
| 41 | 77 | | -15.82588 | 34.98312 | 1 | 29 |
| 42 | 118 | Nambela | -15.82657 | 34.98083 | 1 | 29 |
| 43 | 207 | Nanguna | -15.820251 | 34.982745 | 2 | 30 |
| 44 | 88 | Matambo | -15.82575 | 34.98386 | 2 | 31 |
| 45 | 8 | Dinala | -15.82814 | 34.98137 | 2 | 33 |
| 46 | 110 | Msowoya | -15.82703 | 34.9805 | 1 | 33 |
| 47 | 122 | Bonya | -15.82759 | 34.98038 | 1 | 35 |
| 48 | 100 | Kelvin | -15.82729 | 34.98097 | 1 | 36 |
| 49 | 145 | | -15.82531 | 34.98059 | 1 | 37 |
| 50 | 203 | | -15.819563 | 34.979938 | 2 | 37 |
| 51 | 208 | Kamoto | -15.819846 | 34.982592 | 3 | 37 |
| 52 | 151 | Chigumula | -15.82527 | 34.98182 | 1 | 41 |
| 53 | 65 | Chidowa | -15.82836 | 34.98029 | 1 | 46 |
| 54 | 50 | Chiputula 2 | -15.82838 | 34.97995 | 2 | 47 |
| 55 | 73 | Mkombezi | -15.8283 | 34.97826 | 3 | 47 |
| 56 | 146 | | -15.82541 | 34.9808 | 1 | 47 |
| 57 | 54 | Machinjiri | -15.82799 | 34.98057 | 1 | 49 |
| 58 | 202 | | -15.819534 | 34.980143 | 1 | 49 |
| 59 | 78 | Devison | -15.82628 | 34.98323 | 2 | 51 |
| 60 | 66 | Mwalimu 1 | -15.82872 | 34.97857 | 2 | 53 |
| 61 | 87 | Malata | -15.82592 | 34.98365 | 1 | 53 |
| 62 | 188 | | -15.819077 | 34.983723 | 1 | 53 |
| 63 | 198 | | -15.81995 | 34.980082 | 1 | 54 |
| 64 | 58 | Govati 3 | -15.82859 | 34.97898 | 1 | 56 |
| 65 | 99 | Nkhoma 3 | -15.82721 | 34.98114 | 3 | 58 |
| 66 | 124 | Nyoni | -15.82781 | 34.97997 | 1 | 59 |
| 67 | 187 | | -15.818945 | 34.98333 | 1 | 59 |
| 68 | 159 | | -15.821195 | 34.982315 | 1 | 62 |
| 69 | 201 | | -15.819651 | 34.980191 | 1 | 62 |
| 70 | 113 | Movilikana | -15.82269 | 34.98017 | 1 | 64 |
| 71 | 153 | | -15.82571 | 34.98195 | 3 | 66 |
| 72 | 23 | Mnaosa | -15.82788 | 34.98126 | 2 | 67 |
| 73 | 142 | | -15.8259 | 34.98075 | 2 | 67 |
| 74 | 64 | Sandram | -15.82809 | 34.98055 | 2 | 68 |
| 75 | 31 | Kapachika | -15.82918 | 34.98117 | 1 | 69 |
| 76 | 75 | Gama | -15.82821 | 34.97981 | 2 | 70 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 77 | 119 | Mzuze | -15.82659 | 34.98093 | 1 | 71 |
| 78 | 209 | | -15.8198 | 34.982675 | 1 | 72 |
| 79 | 41 | Micheus 2 | -15.82885 | 34.97997 | 1 | 74 |
| 80 | 131 | Labala | -15.8259 | 34.98013 | 2 | 74 |
| 81 | 155 | | -15.82587 | 34.98229 | 2 | 74 |
| 82 | 191 | | -15.819118 | 34.984143 | 1 | 75 |
| 83 | 90 | | -15.8261 | 34.98289 | 1 | 76 |
| 84 | 55 | Tchire | -15.82942 | 34.97912 | 1 | 77 |
| 85 | 83 | | -15.82548 | 34.98429 | 3 | 77 |
| 86 | 98 | Nkhoma 2 | -15.82713 | 34.98108 | 2 | 77 |
| 87 | 152 | | -15.82506 | 34.98169 | 1 | 77 |
| 88 | 96 | Nyimba | -15.82686 | 34.98096 | 2 | 78 |
| 89 | 133 | | -15.82533 | 34.97928 | 4 | 78 |
| 90 | 34 | Kaligomba | -15.82885 | 34.98079 | 1 | 79 |
| 91 | 1 | Kambalame | -15.82847 | 34.98132 | 1 | 80 |
| 92 | 154 | | -15.82587 | 34.98214 | 1 | 80 |
| 93 | 199 | | -15.820166 | 34.980243 | 1 | 80 |
| 94 | 21 | Kakhuni | -15.82787 | 34.98157 | 1 | 81 |
| 95 | 12 | Khwekhwele | -15.82602 | 34.8413 | 1 | 82 |
| 96 | 11 | Munthali | -15.82648 | 34.98432 | 1 | 83 |
| 97 | 60 | Kambwiri | -15.82826 | 34.97907 | 1 | 83 |
| 98 | 108 | Chilemba | -15.82739 | 34.98071 | 2 | 83 |
| 99 | 6 | Phiri | -15.82769 | 34.98194 | 2 | 84 |
| 100 | 51 | Madson | -15.82813 | 34.98017 | 1 | 84 |

## Appendix E: List of random number for non RRWH adopters

| Serial No | Household no | Name | Southern | Eastings | NO HH | Random |
|---|---|---|---|---|---|---|
| 1 | 17 | | -15.82811 | 34.98087 | 4 | 1 |
| 2 | 36 | Banaba | -15.82887 | 34.98016 | 1 | 1 |
| 3 | 88 | Matambo | -15.82575 | 34.98386 | 2 | 1 |
| 4 | 215 | | -15.823609 | 34.981966 | 1 | 1 |
| 5 | 4 | | -15.82818 | 34.9817 | 2 | 2 |
| 6 | 51 | Madson | -15.82813 | 34.98017 | 1 | 2 |
| 7 | 62 | Naisoni | -15.82868 | 34.97943 | 1 | 2 |
| 8 | 140 | | -15.82566 | 34.98086 | 2 | 2 |
| 9 | 174 | Mangani | -15.822532 | 34.982263 | 4 | 2 |
| 10 | 188 | | -15.819077 | 34.983723 | 6 | 2 |
| 11 | 213 | Nalimo | -15.823712 | 34.981556 | 1 | 2 |
| 12 | 13 | Singano | -15.82763 | 34.98454 | 1 | 3 |
| 13 | 27 | Kagwa | -15.82765 | 34.98159 | 7 | 3 |
| 14 | 34 | Kaligomba | -15.82885 | 34.98079 | 1 | 3 |
| 15 | 45 | Longwe | -15.82841 | 34.98103 | 3 | 3 |
| 16 | 150 | | -15.82552 | 34.98175 | 5 | 3 |
| 17 | 44 | Rolent | -15.82839 | 34.9805 | 5 | 4 |
| 18 | 85 | Kamfutso | -15.82603 | 34.98365 | 1 | 4 |
| 19 | 112 | | -15.8277 | 34.9804 | 1 | 4 |
| 20 | 132 | | -15.82593 | 34.97965 | 5 | 4 |
| 21 | 158 | Mangulu | -15.820896 | 34.982359 | 2 | 4 |
| 22 | 176 | | -15.822096 | 34.982464 | 8 | 4 |
| 23 | 197 | | -15.820278 | 34.979768 | 1 | 4 |
| 24 | 102 | Zibomphe | -15.82753 | 34.98114 | 1 | 6 |
| 25 | 1 | Kambalame | -15.82847 | 34.98132 | 5 | 7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 26 | 32 | Nchimwa | -15.82935 | 34.98109 | 1 | 7 |
| 27 | 212 | Mphinda | -15.823704 | 34.981492 | 4 | 7 |
| 28 | 108 | Chilemba | -15.82739 | 34.98071 | 2 | 8 |
| 29 | 172 | Lampiyo | -15.822985 | 34.982072 | 1 | 8 |
| 30 | 57 | Govati 2 | -15.82884 | 34.97887 | 1 | 9 |
| 31 | 91 | Mwenjemeka | -15.82624 | 34.98287 | 3 | 9 |
| 32 | 152 | | -15.82506 | 34.98169 | 4 | 9 |
| 33 | 153 | | -15.82571 | 34.98195 | 8 | 9 |
| 34 | 194 | | -15.82062 | 34.979995 | 1 | 9 |
| 35 | 210 | | -15.819898 | 34.982844 | 1 | 9 |
| 36 | 226 | | -15.821071 | 34.979981 | 1 | 9 |
| 37 | 175 | Newiri | -15.822421 | 34.982477 | 1 | 11 |
| 38 | 18 | | -15.8282 | 34.98104 | 1 | 12 |
| 39 | 31 | Kapachika | -15.82918 | 34.98117 | 1 | 12 |
| 40 | 111 | Kanada | -15.82712 | 34.98056 | 1 | 12 |
| 41 | 118 | Nambela | -15.82657 | 34.98083 | 1 | 12 |
| 42 | 122 | Bonya | -15.82759 | 34.98038 | 1 | 12 |
| 43 | 134 | Chirombo | -15.82581 | 34.98014 | 4 | 12 |
| 44 | 145 | | -15.82531 | 34.98059 | 2 | 12 |
| 45 | 192 | | -15.819144 | 34.984293 | 1 | 12 |
| 46 | 218 | | -15.821048 | 34.982866 | 3 | 12 |
| 47 | 3 | Yohane | -15.82837 | 34.98183 | 7 | 13 |
| 48 | 138 | | -15.82607 | 34.98403 | 4 | 13 |
| 49 | 142 | | -15.8259 | 34.98075 | 3 | 13 |
| 50 | 166 | | -15.822021 | 34.982781 | 1 | 13 |

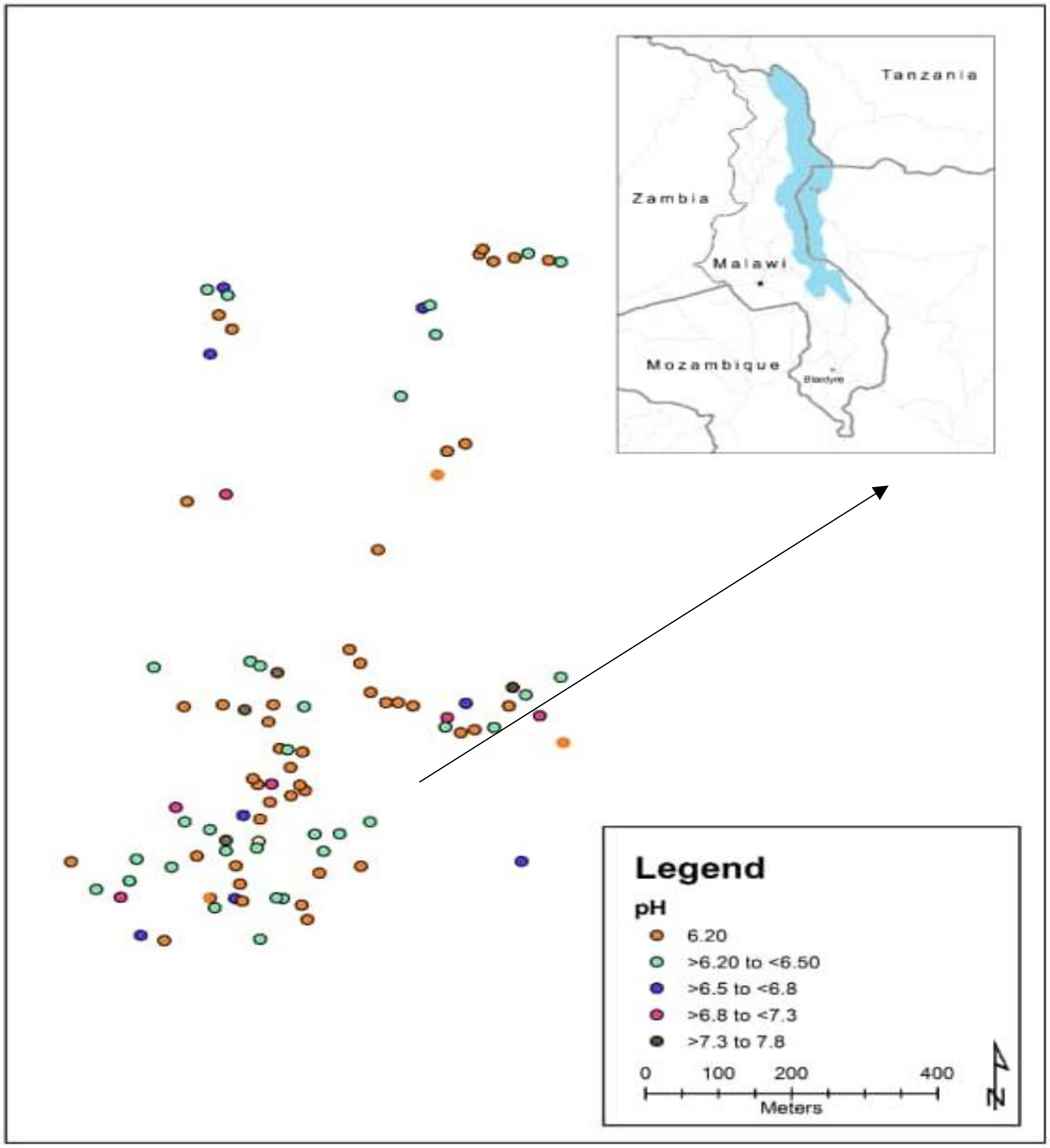
## Appendix F: Components of system design of rooftop rainwater harvesting

**Roof catchment and supporting collecting**

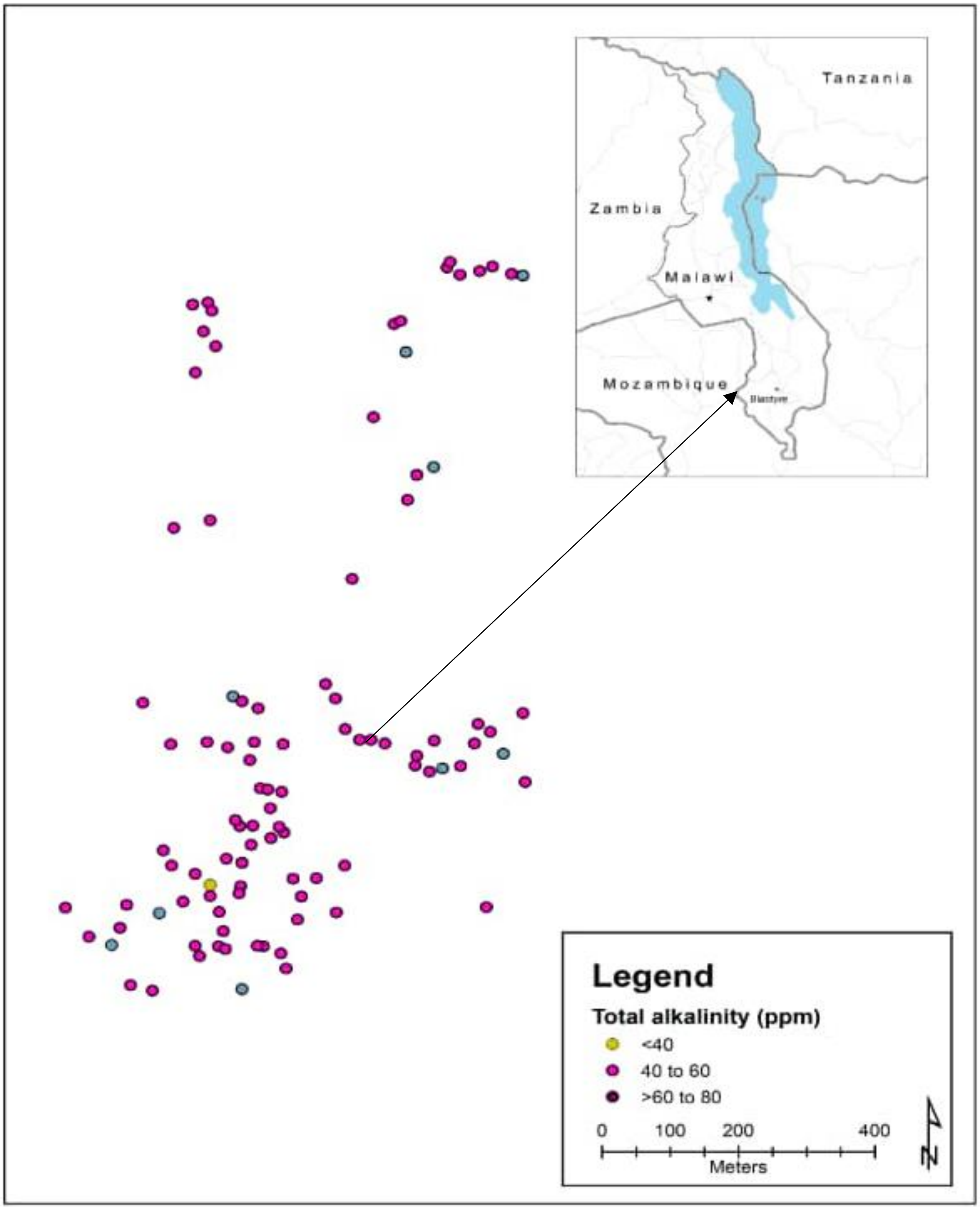
**Supporting collecting**

**Storage devices and capacity**

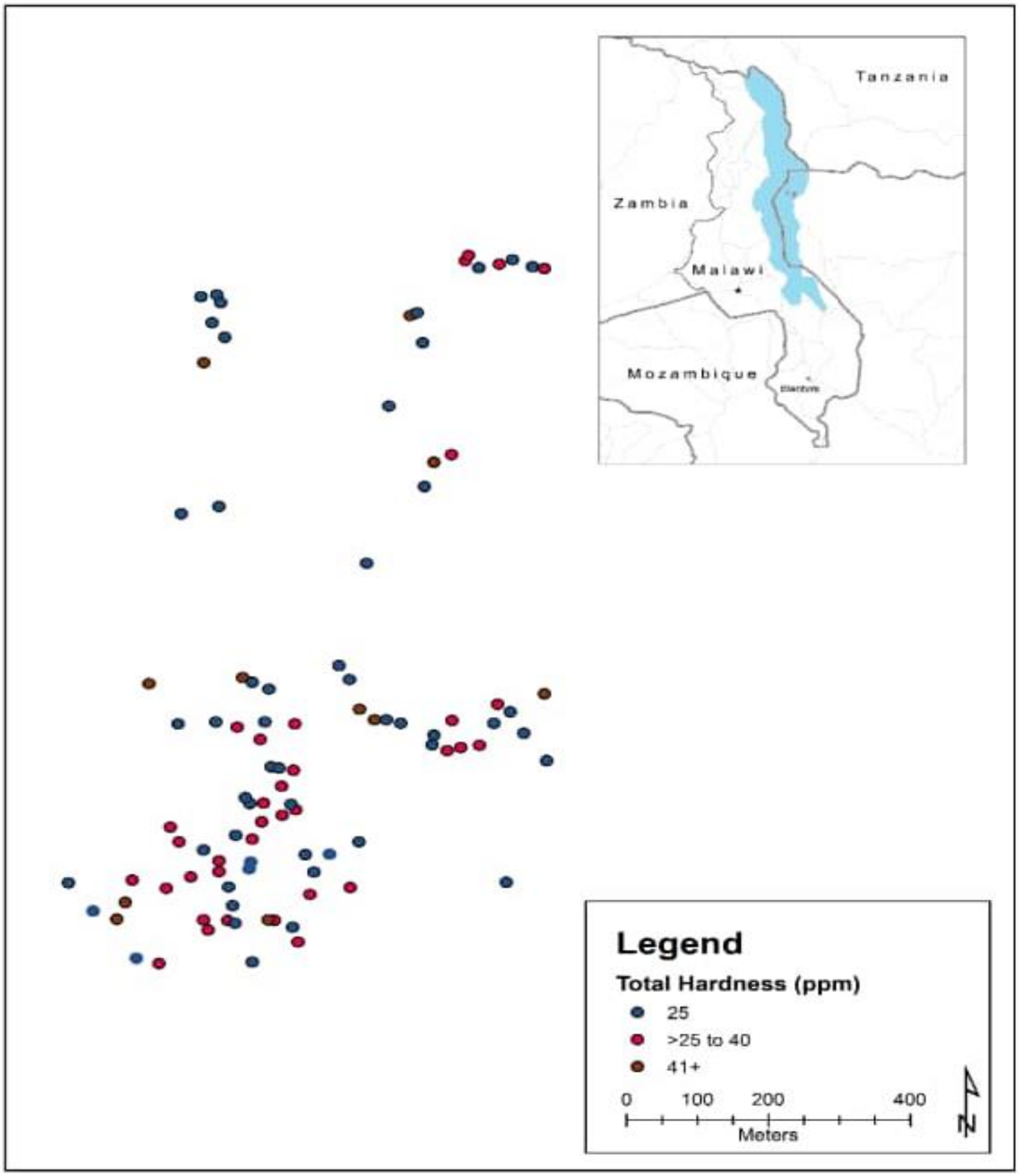
## Appendix G: Distribution of parameters among households



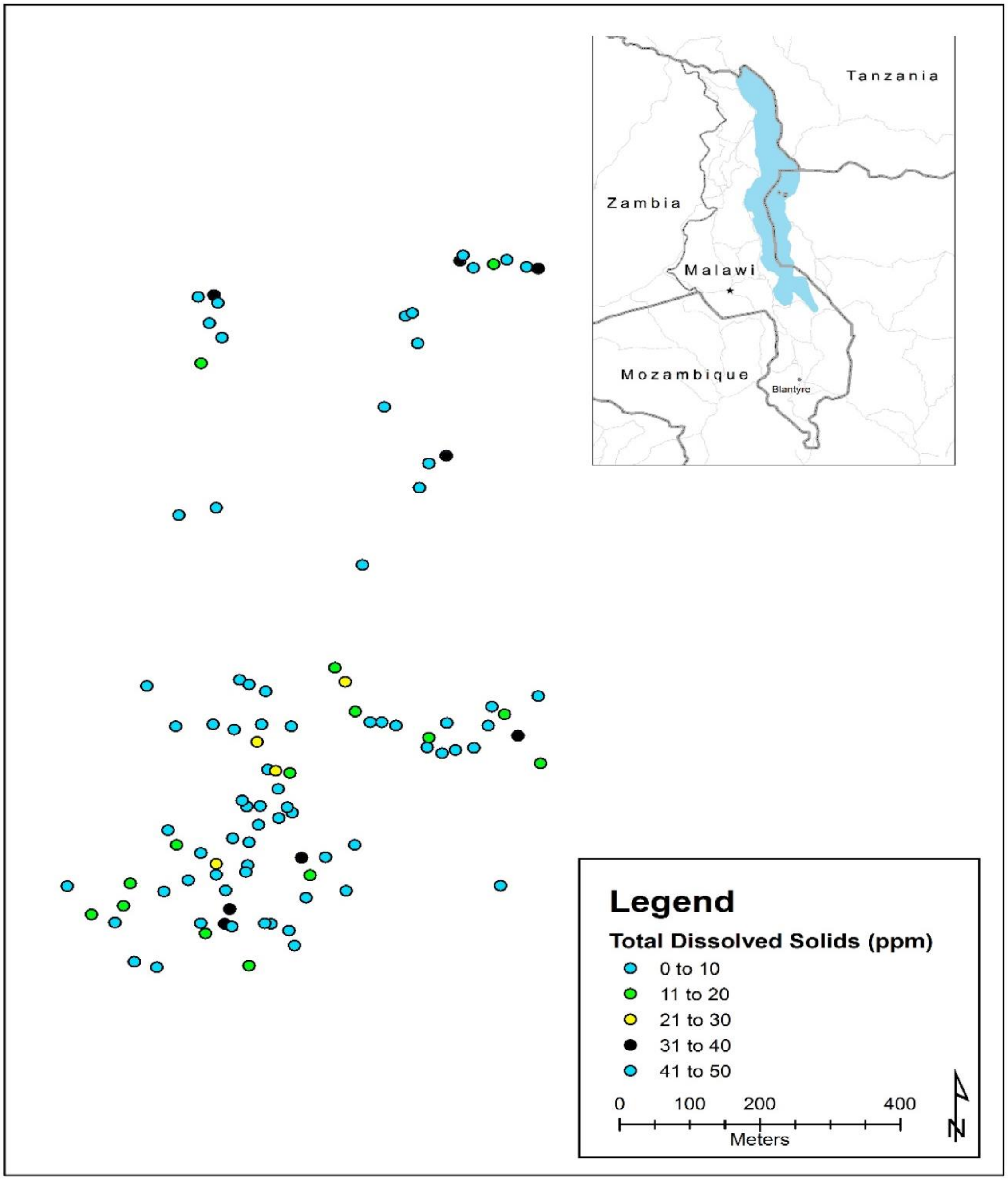

Distribution and variation of pH in Nancholi, Blantyre.



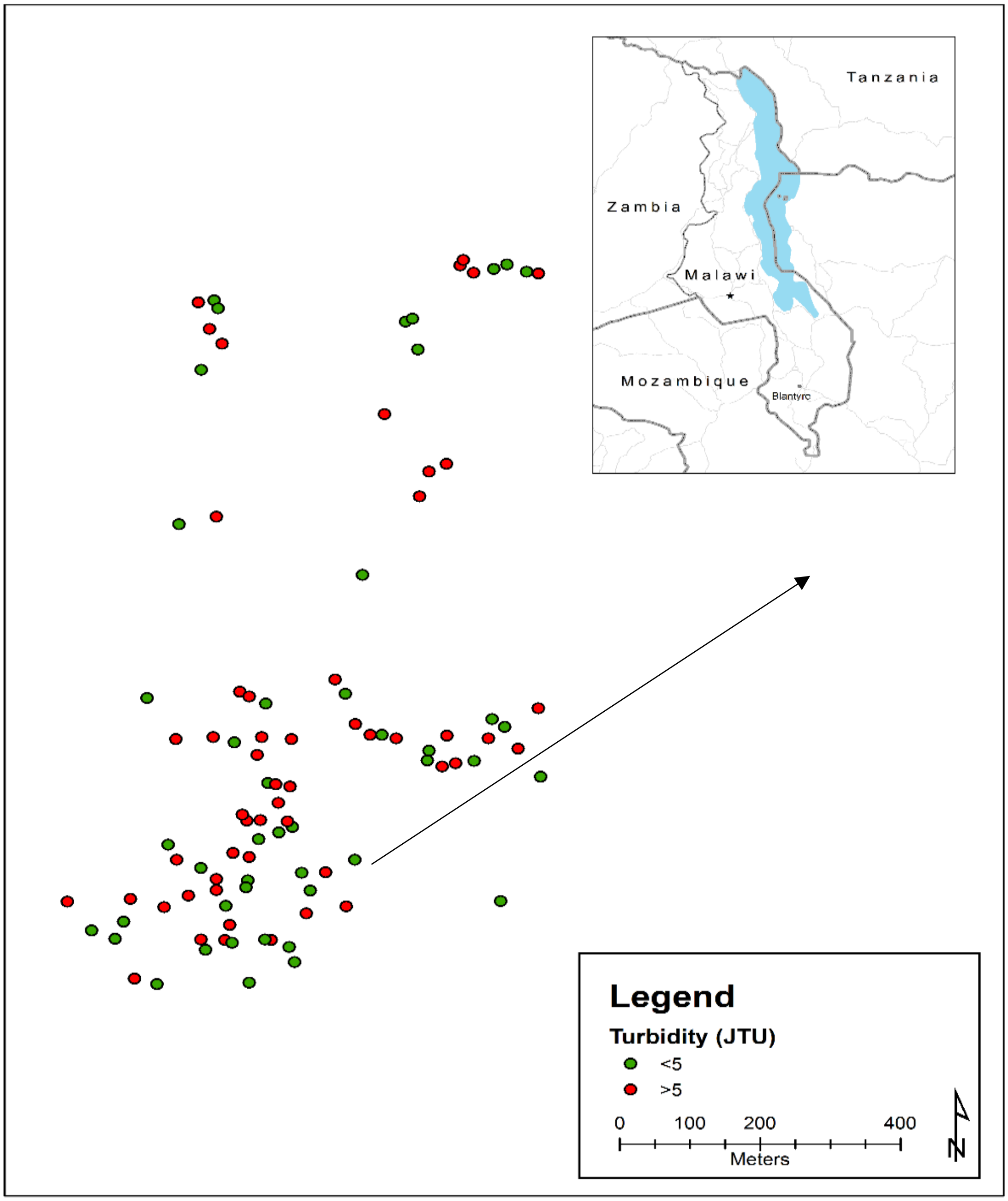
Distribution and variations of total alkalinity (ppm) in Nancholi, Blantyre.



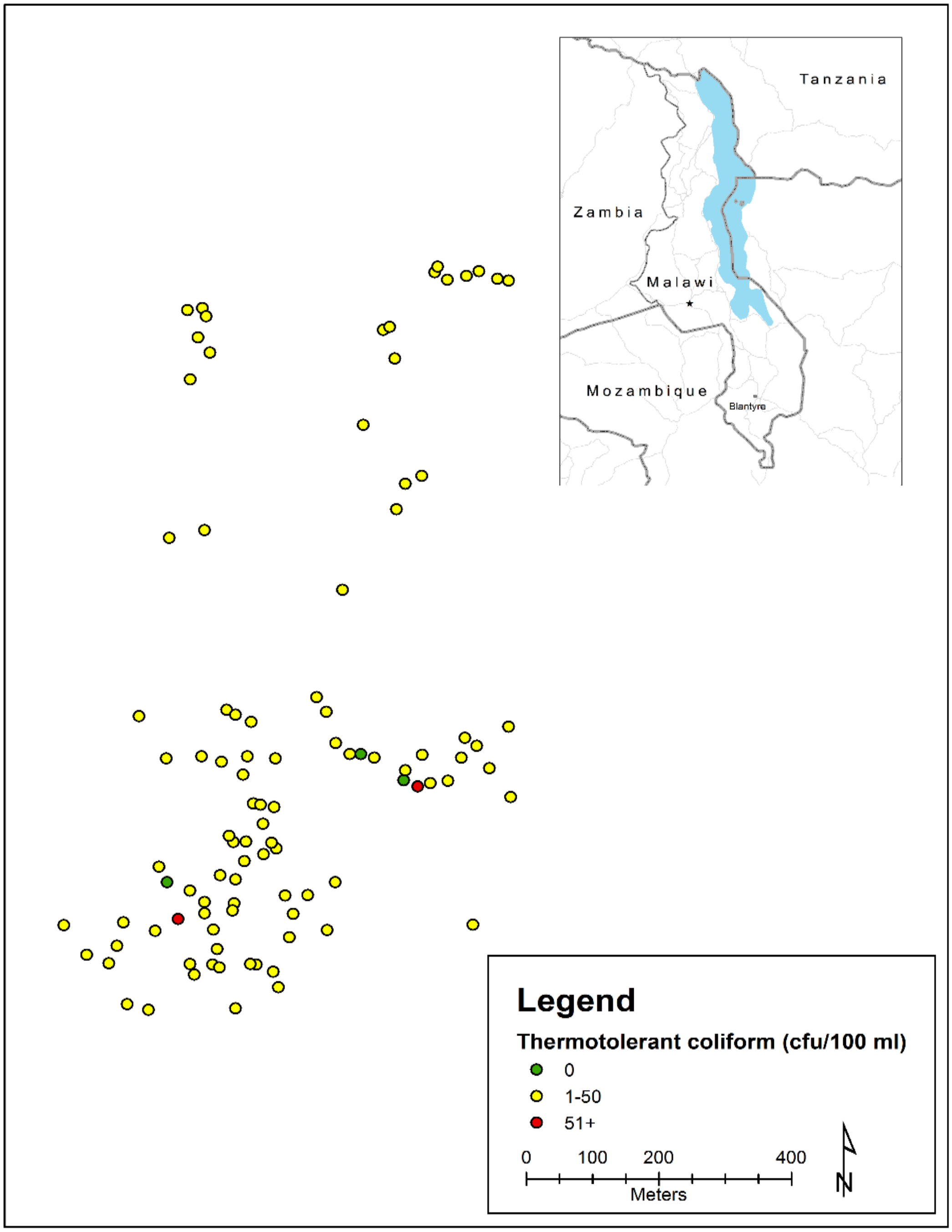

Distribution and variation of total hardness (ppm) in Nancholi, Malawi.




Distribution and variation of total dissolved solids (ppm) in Nancholi, Blantyre.




*Distribution and variation of turbidity (JTU) in Nancholi, Blantyre.*




Distribution and variation of thermotolerant coliform (cfu/100ml) in Nancholi, Blantyre.