UNIVERSITY OF CAPE COAST

RAINWATER HARVESTING IN URBAN GHANA: A CASE OF ADENTAN MUNICIPALITY

EBENEZER TETTEH

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BY

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Thesis submitted to the Department of Geography and Regional Planning of the Faculty of Social Sciences, University of Cape Coast in partial fulfilment of the requirements for the award of Master of Philosophy Degree in Geography and Regional Planning

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: ....

Name: Ebenezer Tetteh

Supervisors' Declaration

We hereby declare that the preparation and presentation of thisthesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: .... Date: ....

Name: Prof. Kwabena Barimah Antwi

Co-Supervisor's Signature: .... Date: ....

Name: Dr. Comfort Ogunyele-Adetona

ABSTRACT

A sufficient, clean drinking water supply is essential to life but millions of people throughout the world do not have access to this basic necessity. Even after the intensive efforts of engineers, planners, builders, governmental and non-governmental organisations (NGOs) to bring potable water to the poorer people of the world, the situation is still a challenge. The problem becomes exacerbated especially in developing countries with an increasing population growth trend. This study sought to assess the potential of rainwater harvesting as a means of augmenting conventional sources of water supply for both portable and non-potable use in the Adentan Municipality. The study involved both adopters and non-adopters of Rain Water Harvesting Technology and adopted the mix method research approach. The study found that more than half of households harvest rainwater on regular basis with rooftop rainwater harvesting as the main technology used. A storage capacity of about 96.2 m^3 or 96200 litres is required to store rainwater. Generally rainwater was assessed to be of good quality, despite some few coliform detected in water samples. Rooftop rainwater harvesting has a great potential of supplementing conventional water supply. The use of a binary logistic regression model revealed that age, sex, marital status, income, and household ownership were statistically significant at 5 percent in explaining households' adoption of RWHT in the Adentan Municipality. It is therefore recommended that all stakeholders in the water sector should ensure that RWHT is incorporated into the design of new and existing buildings, while ensuring that households adopt best management practices that will make rainwater clean and safe to use.

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DEDICATION

To Patrick Tetteh and Mr James Paa Ghartey

TABLE OF CONTENTS

Contents | Page

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ACRONYMS

AfDB	African Development Bank
ADMA	Adentan Municipal Assembly
AMA	Accra Metropolitan Assembly
AMCOW	African Ministerial Council on Water
AWTF	African Water Task Force
BSF	Boisand Filtration
CHC	Canada Mortage and Housing Corporation
CSIR	Council for Scientific and Industrial Research
DRWH	Domestic Rainwater Harvesting
DTU	Development Technology Unit
ECA	Economic Commission for Africa
EU	European Union
GIS	Geographical Information Systems
GPRS I	Growth and Poverty Reduction Strategy I
GPRS II	Ghana Poverty Reduction Strategy II
GPS	Global Positioning System
GWCL	Ghana Water Company Limited
ILWIS	Integrated Land and Water Information System
IRD	International Relief Development
IWRM	Integrated Water Resources Management
MLE	Maximum Likelihood Estimation
MOFA	Ministry of Food and Agriculture
MWRWH	Ministry of Water Resources Works and Housing
NEPAD	New Partnership for Africa's Development

pH	Hydrogen Potential
RELMA	Regional Land Management Agency
RWH	Rainwater Harvesting
RWHT	Rainwater Harvesting Technology
TMA	Tema Metropolitan Assembly
UNEP	United Nations Environmental Programme
UNICEF	United Nations International Children Educational Fund
W HO	World Health Organisation
WRDF	Water Resources Development Fund

CHAPTER ONE

INTRODUCTION

Background to the Study

The survival of every society depends on natural resources (Brondizio & Moran, 2012). Among the available natural resources, water is very important to humans because it is an indispensable commodity to every society without which life will be unbearable for all living things (Caribbean Environmental Health Institute, 2006). Water and life therefore represent the same value and as such inadequate access to safe water makes life worse (Muta'aHellandendu, 2012; United States Agency for International Development, 2013).

In recognition of the importance of water in the global community, the International Drinking water and Sanitation Decade which covered the period 1981-1990 was initiated (United Nations Human Rights Council, 2015). The fundamental objective of this programme was to focus much attention on harnessing resources to reduce the global problem of inadequate water supply by ensuring that there is adequate potable water that is accessible to all regions globally (Johnston, Hiwasaki, Klaver, Castillo, & Strang, 2011).

Water is considered as a basic human right. In other words, everyone has the right to water supply in terms of quality, sufficiency, accessibility, affordability and continuity irrespective of age, gender and among other forms of social group an individual belongs in society (United States Agency for International Development, 2013). In view of this, there should be water at all times for human use. Hence, the Millennium Development Goal aimed at promoting a sustainable environment had the targets of reducing the proportion of people that lack access to safe and adequate water supply to 50 percent and 75 percent by the year 2015 and 2025 respectively (Prokopy, 2005; Osumanu, 2010).

When population was relatively smaller with low urbanisation, natural sources of water such as rivers, streams, lakes, wells, springs, and ponds were capable of providing safe and adequate water supply for all social and economic activities (Pedley, Pond, & Eadaoin, 2011). Most of these water resources have being polluted due to the rapid rate of population growth especially in urban areas and human activities such as deforestation, agriculture, mining and rapid urbanisation (Hashemi, 2012).

Aside human impact on the environment, variations in climatic elements in many parts of the world have made the situation worse (United States Environmental Protection Agency, 2014). The primary source of all water resources is derived from rainfall; however, rainfall pattern in recent years is unevenly distributed across all regions of the world. The spatial and temporal variations of rainfall do not make it possible to adequately meet the water needs of the world's growing population (Coelho & Reddy, 2004).

As a result of this ongoing situation, water resources have being unsustainable in terms of providing clean water supply to meet the needs of present generations without compromising that of future generations (Sustainable Land and Water Management, 2009). In response to the challenges natural water resources face, many countries have adopted conventional methods of providing water by purifying natural sources. Conventional as used in this context refers to water supply through pipes that are provided, treated and supplied under the control of a central authority. All these are part of meeting the millennium development goal which calls for reducing the proportion of people without access to water by one-half in the year 2015.

Despite all efforts being made, conventional water supply approach has being inadequate and unreliable in terms of production and equitable distribution (Nelson, 2012). The main challenges facing conventional water supply systems include rapid population growth that most often lead to excess demand over supply and the problem of getting technical experts. Also, inefficiency issues and inadequate funding also hinder conventional water supply systems from operating at their optimum (Brown, 2012; Daigger, 2009).

The combined effects of human impacts on the environment and climatic variations in terms of drought have led to severe global water crisis especially in developing countries (World Health Organisation, 2009). For instance, in China and India which form the most populous countries in the world, hundreds of cities suffer from inadequate water supplies, and the problem intensifies as their populations increase since demand for water increases proportionally with population growth (Spiertz, 2013). Countries in Latin America, East Africa, North African and Sub-Saharan Africa also face similar water shortages. The African continent has about 3991 km^3/year of renewable freshwater resources (Munyao, 2010) that if well managed can help alleviate countries within the continent from severe water crisis, yet they suffer from water scarcity. This situation has being partly attributed to poor temporal and spatial distribution rather than absolute lack of water.

Ghana like any other African country faces the challenge of water shortage that needs quick mitigation strategies to address the issue. Potable water is critical for improved health and for the pursuit of various socio-economic activities however, many urban communities in Ghana lack adequate access to potable water (Opare, 2011).

Inadequate water supply has a lot of negative impacts on social and economic activities as well as the environment. Despite substantial humanitarian endeavours over the last three decades, almost 900 million people lack access to safe water (Muta'a Hellandendu, 2012). In addressing this situation, there have being collaborative efforts among both governmental and non-governmental organisations. Examples in Africa include the African Ministerial Council on Water (AMCOW), the New Partnership for Africa's Development (NEPAD), the Economic Commission for Africa (ECA), the African Water Task Force (AWTF) and partners such as the UN-Water, UNEP, UN-Habitat, the African Development Bank (AfDB) and several others (Water Resource Development Fund [WRDF], 2008).

In spite of humanitarian efforts made by organisations to curb water crisis, projections made by about 23 United Nations agencies indicate that an estimated two billion people will lack access to safe drinking water by the middle of this century due to the rapid deteriorating global water supply situation (UNEP, 2009). Statistics show that the worldwide death toll associated with the problem of water shortage is around 3.5 million each year;

half of the people involved are children under the age of five (World Health Organisation, 2011). Women and children are the primary victims in particular, the lives and education of girls are impacted the most because they are the key people responsible for supplying water at homes (UNICEF & WHO, 2012). Within the African continent available information shows that about one third of the population lack safe drinking water, and it is estimated that 25 countries will be experiencing water shortages by the year 2025 (UNESCO, 2014). According to Ki-moon (2011), United Nations Secretary General, shortage of water contribute to poverty that causes social hardship and impede development and create tensions in conflict prone regions. "Where we need water we find guns, but irrespective of these impacts there is enough water to satisfy the needs of everyone so long as we keep it clean, use it more wisely, and share it fairly".

Addressing the issue of global water crisis has called for proposals and concepts aimed at developing an integrated and a sustainable water management strategy to mitigate water shortages (Anglian Water Services, 2014). An alternative approach to the problem of limited access to water paved the way for identification and utilisation of additional sources of water that supplement existing sources (Baguma, Loiskandl & Jung, 2010). Rainwater harvesting and storage has being recognised as one way of mitigating the problem of increasingly global water shortages in many countries.

Rainwater harvesting is simply the process of capturing, conveying, and storing rainwater for future use (Andersen, 2014). It is the deliberate collection of rainwater from a surface known as catchment and storing in physical structures or within the soil profile. The concept of rainwater harvesting dates back over 4000 years (Liaw & Chiang, 2014). Among some of the early places where humans widely practiced this method of water harvesting for millennia are North America (Begashaw, 2005), Egypt, Tunisia, Iraq, Negev Desert of Israel, Edom Mountains of Southern Jordan and Ancient Rome (Habibullah, 2014).

Generally, Rainwater Harvesting system has four main components which are; catchment area, conveyance or conduit, filter and storage with a distribution system. Rainwater may be harvested from roofs, ground surfaces as well as from ephemeral water course. However, rooftop harvesting structures have the advantage to collect relatively clean water, while weirs and dams on ephemeral water courses can store relatively larger volumes and for longer periods.

The benefits of harvesting and utilising rainwater have received recognition by international organisations such as the (UNEP, 2006) which stress the need to encourage rainwater harvesting as an alternative option. Currently, rainwater harvesting is being practiced in many countries around the world to provide affordable water for household use, agriculture, environmental flows (timing and quality of water required to sustain fresh water and estuarine ecosystems) and prevention of flood damage (Daigger & Crawford, 2007). A few and notable examples of these countries include Germany, Japan, Singapore, Australia, Algeria, Bahrain, Iran, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Syria, Tunisia, the United Arab Emirates, Yemen and many towns and cities in China and India (Yemenu, 2014).

Though these technologies are considered to offer benefits in terms of accommodating growing water needs and decreasing peak demand from conventional water supply, there are few cases of contamination of water arising from the surfaces used (Begashaw, Evaluation of Rainwater Harvesting Systems in Amhara Region: A Case Study in Libokemkem Woreda. M.sc Thesis Submitted to Haramaya University, 2005). Other structural failures are connected with poor design, water lose due to evaporation and seepage, low technical capacity and subsequently low adoption by users (Asegedew, 2005). These are challenges though, associated with water harvesting it has been proved as a sustainable means of alleviating the malaise of perennial water shortages. As a result of this, many countries have adopted this method and have being successful. Few examples of these countries include Japan, Kenya, South Africa, Ethiopia, Uganda and Burkina Faso (WaterAid, 2013).

In Ghana, rainwater harvesting which has the potential of providing potable water for both rural and urban communities was identified and approved as one of the technological options available to solving perennial water shortages by GPRS I and GPRS II, Water Aid Ghana and the Community Water and Sanitation Agency since its inception in the year 1994. The main focus was to provide potable and adequate water supply to rural communities. Apart from this, Ghana's Water Vision for 2025 has as its main objective to promote an efficient and effective management system and environmentally sound development of all water resources in Ghana (Ministry of Water Resources, Works and Housing, 2010). For the nation to achieve the above objective and to respond to current priorities, it is important to adopt a holistic approach to water resources management and development. Adopting

Integrated Water Resources Management (IWRM) will enhance sustainable management of water resources and provide appropriate decision support systems for valuating competing uses of water (Ministry of Water Resources, Works and Housing, 2007).

One of the reasons why Ghana and many other countries have being advocating the use of rainwater harvesting with slow progress has being lack of tangible scientifically verified information which can be used to demonstrate the areas where rainwater harvesting can be applied. Probably, few studies have evaluated rainwater potential at an urban or regional scale. The need for information in user-friendly formats and which is easy to update, query, manage and utilise, has popularised the use of Geographic Information Systems (GIS) (RELMA in ICRAF & UNEP, 2005). Geographic information system technologies have often being applied to process and analyse complicated spatial data and visualize results in site selection and potential assessment of water (Bakir & Xingnan, 2008).

Although Ghana is on track in achieving the Millennium Development Goal by providing access to water supply to one half of the population by the end of 2015, many urban areas within the country do not have access to adequate and clean water from the national network. Moreover, in areas served by the Ghana Water Company Limited, water service is mostly erratic and increasingly unreliable. Available evidence indicates that only 59 percent of urban residents have access to improved drinking water (Ainuson, 2010).

The inadequacies in urban water supply are felt disproportionally in disadvantaged or peri-urban communities. Also, the needs of the disadvantaged communities are hidden in the aggregate statistics of the larger urban areas. This is due to the high concentration of low income dwellers, squatter communities and poor infrastructure developments in areas without adequate access to water (Ainuson, 2010).

Statement of the Problem

Potable water is critical for improved health and for the pursuit of various socio-economic activities. Despite its immense usefulness, many urban communities in Ghana do not have adequate access to potable water. The availability of a clean, safe and secure water source has being and will always be a major concern for human populations.

Although statistics show that Ghana has gone beyond the expected target of providing urban water supply (National Development Planning Commission, 2015), however, despite all efforts made by government to mitigate the inadequacies in water supply system, the reality is that many people in Adentan do not have water running through their taps. Access to centralised water supply is rare in the Adentan Municipality before the recent completion of the Kpong Dam in 2014. As such, residents in the municipality have been facing severe water crisis over the years (Adentan Municipal Assembly, 2014).

Due to the ongoing water crisis, some people have resorted to various modes of getting access to water supply from bore holes, wells, water tanker operators, sachet water and rainwater harvesting. In spite of all efforts made by government and non-governmental organisations, water supply in the municipality has being inadequate. This is due to deplorable conditions of most pipe lines that connect water in the municipality since they were laid down several decades ago (Adenta Municipal Assembly, 2014). Moreover, the Municipal Assembly did not take into consideration measures to repair malfunctioned pipe lines and extension of pipe lines into new developed areas before the Kpong Water Supply Expansion project was completed to extend water supply to the municipality.

Rainwater harvesting has the potential to generate enough water to supplement existing water sources. Although rainwater is being harvested in the municipality, the extent of harvesting is unknown and may be on individual basis. The use of an integrated approach to harvest water at an urban scale has therefore become a critical issue for sustainable development (UNDP, 2013) in the municipality since it has the potential of augmenting other sources of water supply and ensuring water security in the municipality.

In addition, some studies have been published on rainwater harvesting in urban areas in Ghana (Owusu & Teye, 2015) but few studies focuses much attention on incorporating the use of spatial technology in assessing the potential of rainwater, the extent at which rainwater is being harvested and the factors that either motivate or discourage urban dwellers to adopt rainwater harvesting techniques. Hence, identifying factors that contribute to the collection and use of rain water will have a great impact towards facilitating strategies that can increase its exploitation and thereby improve the quality and availability of water in the municipality.

Objectives of the Study

The main objective of the study was to assess rainwater harvesting as a supplement to alternative sources of water supply to address the perennial water shortages in the Adentan Municipality. The study sought to;

1. Assess the extent of rainwater harvesting in the municipality;
2. Determine the storage capacity required to store rainwater by households in the municipality;
3. Investigate the quality of harvested rainwater in the municipality;
4. Estimate the amount of potential rainwater that can be harvested using rooftops in the municipality; and
5. Determine factors that influence the adoption of rainwater harvesting technologies.

Research Questions

The study was guided by the following research questions;

1. What is the extent of rainwater harvesting in the municipality?
2. What is the average storage capacity required by households to store rainwater based on water supply?
3. What is the quality of harvested rainwater in the municipality?
4. What amount of potential rainwater can be harvested using rooftops in the municipality?
5. What factors influence the adoption of rainwater harvesting technologies?

Significance of the study

Adequate knowledge on rainfall pattern will help in the proper design of rainwater harvesting systems. The analyses of rainfall pattern in the study will provide adequate knowledge on the trend and variability of rainfall in the municipality since rainwater harvesting depends mainly on availability of rainfall. Adequate knowledge on periods or months in which rainfall shows either an increasing or a decreasing trend will serve as a guide to urban dwellers to know the particular months which are viable for water harvesting in terms of water availability. In addition, knowing the pattern of rainfall will help in designing water harvesting systems, especially storage facility size to ensure maximum water collection and reduce excessive water spillage which leads to loss of rainwater due to smaller storage or tank size.

It is hoped that the study will also enhance awareness creation on the need to harvest rainwater in the municipality. Although rainwater is being harvested in the municipality, but there is no published study as at the moment and many people will be unaware of the multiple benefits associated with rainwater harvesting. Therefore the study will serve as a means of explaining the need to accept and harvest rainwater through all forms of education.

The successful completion of this study can also help to reduce household expenditure when people know the essence of harvesting rainwater and practice it. It means therefore that the portion of household budget allocated for buying water from alternative sources will be reduced as there is water available and closer to a facility (Islam, Chou, & Kabir, 2010). Time spent by people in search of water, especially women and children will also be minimised. This will enhance productivity and also reduce lateness and truancy among school children.

The study will also provide useful information on some of the factors that influence the decisions of urban dwellers about their readiness to accept and adopt the technology as an efficient means of supplementing water shortages. It will unravel the challenges such as the cost involved in installing rainwater harvesting system and the technology involved in installing a water harvesting component at household level. This will help decision makers to know how to address these issues at household level and also when implemented at the community or municipal level in order to ensure the sustainability of such projects to benefit all and sundry.

Findings of the study will also inform stakeholders like ADMA and Ghana Water Company (GWC) to formulate and implement best measures to reduce water insecurity in the municipality. This can be in the form of incorporating rainwater harvesting systems in the designing and building of new houses while ensuring that old buildings are also renovated by adding rainwater harvesting components.

The study will also add to literature and serve as a basis for further studies by colleagues who want to undertake similar studies in academia. This could be used in the review of literature and also making inferences based on the major findings related to ones area of study.

Delimitation of the study

The study was confined within the urban areas of Adentan municipality with the primary concern of assessing the potential of rooftop rainwater harvesting technology since the municipality experiences perennial water shortages. Household with storage facilities and gutter or conveyance installed on the roof was classified as an adopter of rainwater harvesting technology while a household without a storage facility and a gutter was classified as a non adopter of rainwater harvesting technology in the study. Respondents were selected at the household level because it is the responsibility of the head to provide water for his or her dependants. Estimating the size of rainwater storage facility was done using the average rooftop in the municipality and did not consider estimating it for individual rooftop captured since the area is relatively large.

The results obtained from the study shall be applicable to the municipality alone; however, the findings can be use in making inferences to other adjoining districts or municipalities with similar problems of inadequate water supply. The findings that emerged from the sample size drawn for the study were used as a representative for the entire municipality.

Limitations of the study

Potential harvested rainwater was computed for the entire municipality based on rainwater supplied by rooftop. This did not take into consideration the water demand side due to inadequate data available on water demanded in the municipality. In view of this, Potential rainwater savings could not be computed. Household data collection remained another key challenge because some respondents who could read and write provided wrong responses that were inconsistent especially in the case of questions with follow-up questions.

Organisation of the Study

The study is organised into five chapters and has being outlined as follows: chapter one forms the introductory part and presents the background information to the study, statement of the research problem, research objectives, research questions, significance of the study and organisation of the study. The chapter again delves into the discussion of the research problem and gives the dimension of the problem.

Chapter two gives the theoretical background and conceptual issues that inform the study. It provides a thorough review of relevant literature covering the concepts and variables that are being considered in this study. Related and relevant materials include relevant books on rainwater harvesting with much emphasis on urban areas, both published and unpublished reports and articles on rainwater harvesting, newspapers and other internet sources that are relevance to the study.

Chapter three describes the methodology used in the study and has being divided into two parts. The first part introduces the study design that was adopted, a brief description of the study area and target population used to draw the sample size for the study. The latter part of the chapter comprises the sources of data for the study, sampling and sampling procedures within the target population, and data collection procedures for both quantitative and qualitative data and data analysis techniques.

Chapter four then discusses the results and analyses of the study. In this chapter, five main areas are covered. These areas are the extent of rainwater harvesting, rainwater storage, quality of harvested rainwater, the amount of potential rainwater that can be harvested using rooftops and factors that influence households' decisions to adopt rainwater harvesting technology in the Adentan Municipality.

Chapter five reviews and summarises the findings of the research; gives possible recommendations based on the specific objectives to planners, policy makers, possible directions for further studies and conclusion.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Introduction

This chapter presents a review of literature on rainwater harvesting, theoretical and conceptual framework that informs the study on rainwater harvesting. The chapter also addresses definition of some basic concepts related to rainwater harvesting. Generally, this chapter is divided into two main parts. The first part delves into extensive review of literature related to the specific objectives of the study. Specifically, the areas that were covered include the extent of rainwater harvesting (the technology being used, storage facilities, water quality), benefits of water harvesting, estimation of potential rooftop rainwater using GIS and factors that influence households decisions to adopt rainwater harvesting as an alternative source of water to augment other sources of water supply. The second part deals with theoretical issues and conceptual frame work of the study.

Definition of Rainwater Harvesting

Rainwater harvesting (RWH) basically consists of the collection, storage and subsequent use of captured rainwater as either the main source or as a supplementary source of water for potable and non-potable uses (Fewkes, 2006). Kahinda, Lillie, Taigbenu, Taute, and Boroto (2008) also defined rainwater harvesting as the collection, storage and use of rainwater for small-scale productive purposes. This definition of rainwater harvesting was limited to only small scale agriculture purposes and did not consider other aspects.

Mati et al (2006) also defined RWH as the deliberate collection of rainwater from a surface known as catchment and its storage in physical structures or within the soil profile. Based on the few definitions, Rain water harvesting refers to the technology used for capturing or collecting and storing of rainwater from rooftops, land surface (steep slopes, road surfaces or rock catchments) using simple techniques such as pots, tanks or cisterns as well as more complex systems such as underground check dams.

History of Rainwater Harvesting

Storage of rain water in small ponds, tanks or cisterns has being practiced widely throughout the world for millennia. The history of rainwater harvesting dates back into ancient times and has being practiced by many ancient civilisations for over millennia to meet plant-cultivation, human, and animal needs (Mohammad, Bahram, & Fereshte, 2013). Some of the earliest known rainwater harvesting systems are found in Asia (United Arab Emirates, Israel, Jordan, Palestine, India and China), Africa (North, East, South and West), South America (Latin America), North America and Europe (Mays, Antoniou, & Angelakis, 2013). Archeological surveys in the Middle East discovered the remains of a RWH system in the form of reservoir and underground cisterns dating from 9,000 years ago in Edom Mountain, Southern Jordan. In India, a basic stone structure for the purpose of RWH was found that dates back to 3000 BCE. There was an evidence of the Nabataen civilisation dating back to 3000 BCE in the Negev Desert of Israel that used to capture storm water and store it in cisterns (Bruins & Lithwick, 2012).

In addition, there are also pieces of evidence proving that the Ur area in Iraq was practicing simple forms of rainwater harvestin around 4500 BC

(Mbilinyi, Tumbo, Mahoo, Senkondo, & Hatibu, 2005). Harvested rainwater has also being used for agricultural purposes about 4000 years ago in the Negev Desert of Israel (Mays, Antoniou, & Angelakis, 2013). Researchers have also found signs of early rainwater harvesting structures constructed over 9000 years ago in the Edom Mountains of Southern Jordan (Oweis, Prinz, & Hachum, 2012). In North Africa, water stored in tanks has being used for a variety of purposes since the Roman period. Even in recent times some of these tanks are still in operation in Tunisia and Egypt (Andersen, 2014). In sub-Saharan Africa, the growing awareness about the potential of rainwater harvesting for improved crop production was observed prior to the severe droughts that occurred in the 1970s and 1980s which led to crop failures (Yosef & Asmamaw, 2015).

The interest in using rainwater harvesting technologies in North America was also developed during drought periods in the 1930's and has continued since then to provide some levels of agricultural security (Begashaw, Evaluation of Rainwater Harvesting Systems in Amhara Region: A Case Study in Libokemkem Woreda. M.sc Thesis Submitted to Haramaya University, 2005). In the case of Ancient Rome, rainwater was collected from rooftops and used for both domestic and landscape purposes (Mbilinyi, Tumbo, Mahoo, Senkondo, & Hatibu, 2005). Rainwater harvesting is practiced on a large scale in Bangladesh, and in many Indian cities like Chennai, Bangalore and Delhi where rainwater harvesting is a part of the state policy. Countries like Germany, Japan, and Singapore are also adopting rainwater harvesting (UN-HABITAT, 2005).

Literature suggests that the world's largest rainwater tank is without doubt the Yerebatan Sarayi in Istanbul, Turkey (Mays, Antoniou, & Angelakis, 2013). This was constructed during the rule of Caesar Justinian (A.D. 527-565). It measures 140 m by 70 m and has a capacity of 80000 cubic metres. Basically, Rainwater harvesting system has four main components and these are; catchment area or surface, conveyance with filter, storage facility and distribution system.

Components of Rainwater Harvesting System

Catchment Surfaces used in Rainwater Harvesting

In rainwater harvesting, runoff can be collected from different catchment surfaces such as impermeable areas like car parks, streets, roads, pavements and roofs (Fewkes, 2006). However, in urban areas the catchment surfaces that are commonly available and used to provide cheap and clean water are rooftops (Hassell, 2005). It must be noted that collection of all rainwater falling on catchments is impossible due to the fact that some are lost from the system due to processes such as depression storage, evaporation and splash (Butler & Davies, 2004). Other factors influencing the occurrence of loss of rainwater include rainfall depth and intensity, catchment material, slopes, and other antecedent conditions (Li, Xie, & Yan, 2004).

In rainwater harvesting, the effective runoff is the volume of rainwater falling on the catchment that can be collected and directed into the collection system of gutters and pipes. In order to estimate runoff, a commonly used approach is a dimensionless runoff coefficient that denotes observed losses from the catchment compared with a flawless catchment with no losses (Fewkes, 2006). Effective runoff is estimated by finding the product of the volume of rain falling on a given roof and runoff coefficient. A coefficient value of 0 means there is no runoff, whilst a value of 1 means all the rains falling on the catchment is translated into effective runoff.

Conveyance

Gutters, downspouts, first-flush diverters, and piping are used to channel rainwater from the catchment surface to storage tanks or cisterns. In order to maximise the efficiency of the rainwater harvesting system, a better conveyance system is required to transport the most water that is captured on a given catchment surface during each rainfall event. The sizes of these components aforementioned depend on a number of factors. These include the maximum rainfall rate, the footprint and shape of catchment surface, and the number of points where water is diverted to a storage tank. Although a 4-inch gutter and piping system is adequate to transport water, at least, 6- inch is more preferable as it will yield better results (Texas Commission on Environmental Quality [TCEQ], 2007).

Storage

There are a number of different storage facilities used in rainwater harvesting. The most dominant storage tanks being used in the developed world are underground tanks. On the other hand, in developing countries where income levels are relatively low, surface water tanks dominate (Hassell, 2005). The developed world prefers the underground tanks to the surface tanks because the water tank is protected from extreme weather conditions at the surface, such as freezing spells, preventing algal growth by protecting the tank from daylight (Despins, Farahbakhsh, & Leidl, 2009) which helps in regulating water temperature in the tank, keeping it cool and limiting bacterial growth.

Storage tanks used for harvesting rainwater consist of different sizes and shapes and can be made from a variety of materials like ferro cement, concrete, bricks, steel and plastics such as glass reinforced plastic or high-density polythene (Fewkes, 2006). The storage capacity of tanks for domestic rainwater harvesting systems are in the range of 1-10 m^3, whereas tanks for commercial systems vary from wider range of sizes which can be at least hundreds of cubic metres in volume. In making provision for storage tank in rainwater harvesting, the capacity of the storage tank should be about 20 percent larger than the volume of potential harvested water. For the purpose of this study, only domestic rainwater harvesting storage devices are covered. In view of this, the following storage facilities are mostly used in rainwater harvesting.

a. Surface tanks.

b. Underground tanks.

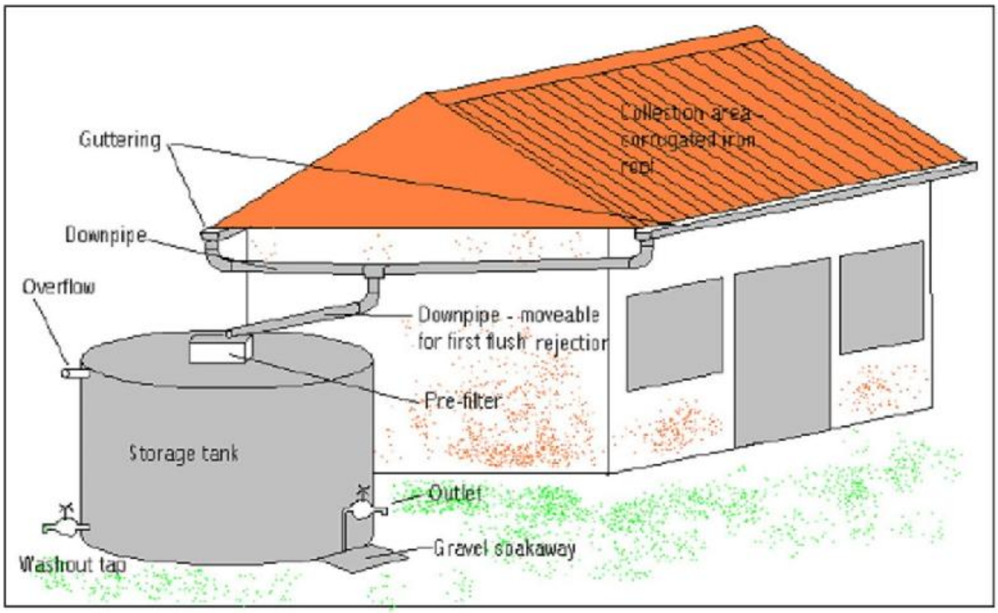
c. Surface reservoirs.

d. Ground-water recharge pits.

Distribution Systems

These are systems that are used to connect storage tank in order to distribute rainwater to main areas that water is required to be supplied to. Distribution systems are determined by location and end use of water. These include all pipes, pumps and other devices that move rainwater from storage, treatment and to the point at which it is finally used.

A simple rainwater harvesting system is shown in Figure 1.


Guttering
Collection area - corrugated iron roof
Downpipe
Overflow
Downpipe - moveable for first flush rejection
Pre-filter
Storage tank
Outlet
Gravel soakaway
Washout tap

e. Treatment/purification facilities: These facilities consist of filters and disinfection equipment that purify untreated rainwater by removing various contaminants and making it safe for potable purposes.

f. Treated water storage and distribution system like storage tanks, service pumps, pressure tanks, and water lines that distribute water to various places for use.

The Design of Rainwater Storage Facilities

According to Fewkes (2006), designing and sizing of rainwater harvesting tanks depend on several factors. Prominent among the factors that tank sizing depends on are rainfall amount and variability, catchment surface (type of roofing material) and adequate information on water demand or daily water consumption of individuals and households.

In recent studies, it has being strongly recommended that a tank should be sized in such a way and manner that it overflows at least twice per year, to enable elimination of floating materials from tanks for unfiltered cases (Brown, 2011). Nevertheless, in many developing countries, the design of rainwater harvesting facilities especially for domestic purposes is often based on traditional methods. This approach is mainly based on only water demand point of view without considering other factors such as the rainfall intensity and pattern of an area, and available roof surfaces that influence the capacity of storage facilities of harvested rainwater. This approach often hinders the full exploitation and utilisation of rainwater in many rural and urban communities.

One of the simplest methods used in estimating the storage size is the use of daily household consumption rate of water and the average length of the longest dry period in a given year. This approach is based on the common assumption that only roof area and rainfall result in producing runoff sufficient to fill a particular storage tank. Determination of tank size for rainwater harvesting storage from the supply side requires the use of complex computation using mean monthly rainfall data and mean monthly water consumption figures.

A graph of cumulative harvested rainwater and cumulative demand are used to estimate the storage requirement that satisfies the consumption rate of a household. This method is suitable for finding the size of tank that is required to store harvestable rainwater for a particular roof area and rainfall pattern that is capable of meeting the water demand for users. This approach of sizing storage tank uses either tables or graphs to calculate the capacity of a given tank in such a way that the harvested rainwater always exceeds the consumption rate of users (World Bank, 1986).

Linsley and Franzini (1987) also used mass-curve analysis technique in their studies to determine the size of water supply reservoirs which proved to be a very efficient method in their analysis. This technique has been applied in the determination of rainwater harvesting tanks size that is needed to meet a specific water consumption rate. The mass-curve analysis is based on the assumption that there is readily available data on roofs and rainfall data of a given geographic area. This method uses time series rainfall data over a period of at least twenty years to estimate the size of water tanks so that all possible variations that occur in rainfall data are captured.

There are several computer-based calculators for determining required storage tank (cistern) size. These methods require daily and monthly rainfall data over a period of at least 20 years to perform reliability analysis of rainwater harvesting systems. Daily rainfall data is most preferred as it provides the most accurate result. Nonetheless, monthly data can be used at instances where there is inadequate access to daily rainfall data. One of these computer-based programmes, written by an Indian organisation is Sim Tanka (Thomas, 2004). This is open source software that takes into account fluctuations in rainfall, to determine the size of rainwater harvesting storage tanks. The outcome of the simulation allows the design of a rainwater harvesting system that meets demands consistently. The data required for Sim Tanka simulation is at least 15 years daily or monthly rainfall data of the area that the rainwater harvesting system is located and daily water consumption per person. The software computes the tank size required based on the required information.

Besides Sim Tanka, the Warwick calculator (Development Technology Unit, 2012) is another computer model that is used in calculating optimal tank size and also evaluating the performance of a given rainwater harvesting system using roof area, daily water demand and rainfall pattern. This is an open-access rainwater harvesting system modeling service that converts the monthly rainfall data to daily values, which are then used in the calculation. Thus, the simulation provides useful information that gives the reliability, satisfaction efficiency and the various tank sizes based on nominal daily water demand of individuals or households.

The International Relief Development (IRD) developed a tool to run tank simulations using daily average precipitation data over long periods of time, catchment area (roof area), number of people per household, water consumption per person per day and a runoff coefficient of 10 percent (percentage water loss). Although the method is very efficient in determining storage size, the only disadvantage is that the simulation has to be done for each roof and not for the total collection of roofs in the study area (International Relief Development [IRD], 2013). This is because harvested rainwater is specific to many characteristics of the household and structures

The use of mathematical models in designing storage size of rainwater harvesting systems has been well noted in several studies. For instance, Ming-Daw, Chun-Hung, Ling-Fan, Jui-Lin and Mei-Chun (2009) developed a method based on probabilistic approach to explore the association between storage capacities and deficit amounts of rainwater harvesting systems in the City of Taipei, Taiwan (Siabi, Van-Ess, Engmann, Mensah & Tagoe, 2008). In exploring the association between the storage capacity and the deficit in water supply, curves were used by engineers in designing the storage size.

Water Demand in Relation to sizes of Rainwater Tanks

According to Siabi et al, 2008 rainwater harvesting storage tanks are usually designed to store enough water any time rainfall is available. Based on the Community Water and Sanitation guidelines (Community Water and Sanitation Agency, 2010) for rainwater harvesting, water demand of 20 litres/person/day is normally used during designing of storage tank, although, the actual daily water consumption per person for communities who rely on water sold by informal water vendors is about 10 litres.

Rainwater Harvesting Technologies

The selection of appropriate rainwater harvesting technology depends on the sources of water supply and mode of storage. According to Sivanappan (2006) and Kunle (2014), there are diverse technologies of water harvesting depending upon the source of water supply and locations as categorised below.

1. In situ Rainwater harvesting. This involves bunding and terracing, vegetative / stone contour barriers, contour trenching, contour stone walls, contour farming, micro catchments, tile ridging methods and farm ponds.
2. Direct surface runoff harvesting. This encompasses roof water collection, dug out ponds / storage tanks, "tankas", "kundis", "ooranis", temple tanks, diversion bunds, and water spreading.
3. Stream flow / runoff harvesting. This involves "nalla" bunding, gully control structures, check dams - (temporary or permanent), silt detention tanks or percolation ponds.
4. Subsurface flow harvesting. This requires subsurface dams and diaphragm dams.
5. Micro catchments / watershed. Examples of these are inter-terrace / inter-plot water harvesting and conservation bench terrace.
6. Runoff inducement by surface treatment consists of eroded catchments, use of cover materials-aluminum foils, plastic sheet, bentonite, rubber, using chemicals for water proofing and to harvest runoff water.

The Canada Mortgage and Housing Corporation (2013) identifies three main conditions that influence the selection of a specific rainwater harvesting technology and the choice of technology also depends on needs of the community and the feasibility of the technology. According to CHC, the existing rainwater technologies vary from one region to another. These three main conditions are outlined as follows.

1. The intended use of the water (drinking water, household use, agricultural purposes).
2. Method of collection which includes fog, roof-top, ground and sub-surface.
3. Method of storage which is also classified as either above ground, partially below ground or underground.

Every particular rainwater harvesting technology has its own advantages and disadvantage associated with it and therefore the technology selection is mainly based on needs assessments and feasibility studies, which take a number of factors such as geographical characteristics of the area, associated costs of the technology, and the ability of the technology to meet the needs of the community.

Rainwater Quality

With regards to rainwater quality, there are no stringent or particular standards for checking water quality since harvested rainwater is used for multiple purposes such as potable and non-potable uses (Despins, Farahbakhsh, & Leidl, 2009). Hence the purpose or water usage determines the type of treatment given to harvested rainwater although there are existing standards such as those of USA Environmental Protection Agency, European Union (EU) and World Health Organisation (WHO) recommendations.

According to Lade (2013), the quality guidelines should be application specific and should also be based on the intended use of rainwater by users. Many studies have confirmed that rainwater is of good quality to meet potable needs of people in several parts of the world. Peter and Mberede (2001) conducted a research on the quality of harvested water using different catchment or surfaces in rural areas of southern Nigeria and found that rooftop has the highest potential of providing about 90 percent of potable source of water. The surfaces used in the study were mainly corrugated metal sheets.

In urban Zambia, a rainwater harvesting system was designed based on mass curve analysis for storage and rational formulae for gutters. Analysis of harvested rainwater samples indicated that it was suitable for drinking purposes (Lubinga, James, & Caroline, 2003). Similarly, Olaoye and Olaniyan (2012) also performed an analysis on rainwater quality from four roofing materials namely; asbestos, aluminium, concrete and corrugated plastic in Ogbomosho, Oyo State. Their analysis of rainwater samples suggested that harvested rainwater when properly boiled could be used for domestic purposes.

In addition, rooftop surface has the potential of providing clean water for domestic use if catchment surfaces and conveyance are cleaned regularly to remove animal faeces and leaves from contaminating the water (Olaoye & Olaniyan, 2012). Still on the quality of water, rainwater samples collected from thatch, aluminium, asbestos, corrugated iron roofing sheets, and open surfaces from roofs catchment in six rural communities of Delta State in Nigeria suggested that rainwater is clean for domestic use. Although, most of the physicochemical and biological characteristics of rainwater samples were below the WHO threshold, there was a satisfactory concentration of rainwater characteristics in the rural communities of the Delta State (Efe, 2006).

Despins, Farahbakhsh and Leidl (2009) examined the quality of rainwater in Ontario, Canada and found out that water from a rainwater harvesting system can be of high quality if only the appropriate catchment, storage unit, and treatment are employed. The mean pH value of 7.3 rainwater quality test indicates that harvested rainwater was perfectly suitable for both potable and non-potable purposes because it was close to the neutral value of 7.0. Despite this pH value, it must be noted that pH is not the determinant of healthy water.

Although studies have shown that rainwater especially from roof catchment surface is often clean for domestic uses, the type of roofing material used also has influence on water quality (Appan, 1999 b). The quality of rainwater may also depend on the geographical location of a particular region and hence rainwater may not be of good quality across all regions (Kyle, 2012). There is therefore the need to treat harvested rainwater well for potable uses.

Rainwater Treatment

In case of rainwater treatment, chemicals are widely used for disinfection purposes. Among these chemicals being used, chlorine is the simplest, most widely used and inexpensive of the drinking-water disinfectants. Chlorine usage is highly effective against nearly all water borne-pathogens, with the exception of Cryptosporidium parvum oocysts and the Mycobacterium species (Clasen & Edmondson, 2006). At household level, tablets or powders that combine a coagulant-flocculant and a chemical disinfectant are mostly used in treating water. The socio-cultural acceptance of disinfection with chlorine-containing components is low in some cases, because of the effect it has on water in terms of taste and odour (Murcott, 2005) households still treat rainwater with other methods like boiling and filtering.

The use of sand filtration has being adapted for domestic use and is known as biosand filtration (BSF). This method of purifying rainwater involves the filling of biosand filters with sand and a bioactive layer is allowed to grow as a means of eliminating disease-causing organisms. Laboratory and field tests have shown that BSF removes about 81-100 percent of bacteria and 99.98-100 percent of protozoa. However, the only major concern with the use of these filters is that it has limited virus-removal efficiency (Lantagne, Quick, & Mintz, 2007).

Erwin (2007) conducted a study on Rainwater Harvesting Potential in Germany and found that polluted rainwater from streets and courtyards could be treated to a certain high quality level with less expensive methods for household use such as washing and toilet flushing. The type of treatment depends on the usage or purpose of which water is being harvested for. Potable water for drinking demands greater care in terms of treatment and non-potable usage demands less or no treatment.

Shittu, Okareh and Coker (2012) designed and constructed a rainwater harvesting system for a household in which there is no public main supply. Their work suggested that rainwater provides a cheap and viable water supply option for domestic, industrial and agricultural purposes for both urban and rural dwellers. Rainwater was used for cooking, drinking, washing and flushing of toilets at home. It is also use for irrigation purposes in urban agriculture whilst in the rural areas, rainwater is used as the main source of water or to supplement other sources.

Benefits of Rainwater

Harvested rainwater has multiple benefits in terms of providing water for both potable and non-potable uses. Generally, Fewkes (2006) identifies three main uses for harvested rainwater as follows:

1. Main source of potable (drinking) water
2. Supplementary source of potable water
3. Supplementary source of non-potable water

Main source of potable (drinking) water

A study in South Africa indicated that rainwater harvesting has the potential of providing water in urban and rural areas that have not being supplied with centralised or conventional water system. The study suggested that domestic rainwater harvesting can be used effectively to achieve this aim in South Africa through the application of a holistic or an integrated approach (Mwenge, Akpofure, Taigbenu, & Boroto, 2007).

Lekwot, Samuel, Ifeanyi and Okisaemeka (2012) also evaluated the potential for RWH in Kanai (Mali) district, Kaduna State and the outcome of their study revealed that the amount of rainwater harvested was sufficient to supplement the needs of rural communities under the condition that there is a massive community participation involved in rainwater harvesting activities in the area.

Lade, Coker and Scridhar (2012) conducted a study on the use of rainwater harvested from rooftops to recharge ground-water in household wells in Ibadan. The study suggests that the use of rainwater for recharging ground-water in wells connected to harvesting systems led to water conservation through reduced evaporation and provided water all the time than the control wells that dried up in the dry season (madhaorao, 2006).

Coker (2001) studied rainwater exploitation as a source of water supply in Akufo, a village in Ibadan, Nigeria and rainwater harvesting was considered as a viable option in the design of a community water supply scheme. The study indicated that rainwater harvesting has a massive potential for providing water to meet the water demand of the rural folks.

Peters (2006) also did a thorough assessment on the potential of rainwater harvesting in the Island of Carriacou, Granada on the Caribbean Island. The findings indicated that although per capita water demand depends largely on household income levels, however, harvested rainwater could adequately meet the water demand of the inhabitants.

Supplementary source of potable water supply

A study on roof water harvesting from high-rise buildings in Singapore where more than 84 percent of the population resides revealed that harvesting rainwater could save about £9,187 of water expenditure each month which could be used for other purposes to improve standard of living (Adhityan, 1999).

In Newcastle, Australia, literature suggests that a study that explored the use of rainwater in 27 houses concluded that rainwater harvesting and its usage would promote potable water savings by 60 percent which is a very economical and efficient means of making use of free water supply while conserving potable conventional water supply (Coombes & Kuczera, 2003).

Ghisi, Montibeller and Schmidt (2006) appraised the potential for potable water saving using rainwater in 62 cities in South-Eastern Brazil. According to their findings, rainwater harvesting has the average potential of saving about 41 percent of conventionally treated water supplied in urban areas.

Ghisi and Oliveira (2007) explored the potential for potable water saving in south Brazil. The findings indicated that the potential for potable water saving using harvested rainwater depends on potable water demand of individuals and households in the cities, however, the potential for potable water savings using rainwater ranged between (34-92) percent.

In Germany, a study on rainwater harvesting revealed that the potential for potable water savings as a result of harvested rainwater in households varies from (30-60) percent, based on demand and roof area (Herman & Schmida, 1999). Besides, the study also found that rainwater harvesting saves money, saves other water sources, reduces erosion and storm water runoff and increases water quality by reducing polluted surface runoff from contaminating other water sources.

Mourad and Berndtsson (2011) examined the potential water savings from rainwater harvesting in Syria and found that roof rainwater has the potential of increasing other sources of water supply to as much as 35 million m^3 in both urban and rural areas.

Supplementary source of non-potable water supply

Harvested rainwater can supply water to augment or supplement alternative sources of water supply in all sectors. Rainwater harvesting increases food production in many areas that face the challenge of acute water shortages. The various techniques been adopted in different part of the world help in addressing the issue of food security.

Shittu, Okareh and Coker (2012) designed and constructed a rainwater harvesting system for a household in which there is no public main supply. Their work suggested that rainwater provides a cheap and viable water supply option for agricultural purposes for both urban and rural dwellers.

Appan (1999 a) examined the use of rooftop water from Nanyang Technological University in China, to provide adequate water supply for toilets facilities in the University campus. The outcome of the study showed that harvested rainwater from rooftops reduced potable water consumption by 12.4 percent which was a way of preserving potable water for future use. Similarly, in Nottingham, United Kingdom, harvested rainwater from roofs was used for flushing toilets in houses. This led to a mean water saving efficiency of 57 percent when the performance of the rainwater collector was monitored. Using harvested rainwater for non-potable purposes saves treated water and household expenditure on water (Fewkes, 1999).

Ghisi, Fonseca and Rocha (2009) assessed the potential for potable water saving using rainwater for washing vehicles in petrol stations in Brasilia, Brazil. Their findings showed that rainwater harvesting has the potential of saving potable water from (9.2-57.2) percent, with an average saving of 32.7 percent.

A study by Mutekwa and Kusangaya (2006) indicates that a successful adoption of RWH technologies in Zimbabwe has contributed to alleviate problems faced by resource poor subsistence farmers. Benefits of RWH technologies include increase in agricultural productivity, enhancing household food security and raising of incomes.

Other benefits of rainwater harvesting

Rainwater harvesting reduces women's and children's burden of collecting water for domestic use in areas where women and children have to travel long distances in search of water when there is water available to supplement other sources. The time saved can be used for other income generation activities like farming and trading. RWH also gives opportunity for the female-child to attend school as most of these children are involved in providing water for their families (Bulos, 2013).

Application of GIS and Remote Sensing Techniques in Rainwater Harvesting

Geographic Information System (GIS) is a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems (Huisman & By, 2009). GIS uses advanced analytical tools to explore at a scientific level the spatial relationships, patterns and processes of cultural, biological, demographic, economic, geographic and physical phenomenon (Bakir & Xingnan, 2008). GIS functions includes; capturing of data, storing data, data analysis, query, data visualization and output of information (Huisman & By, 2009).

Weighted overlay analysis using the GIS software, ILWIS and ArcGIS helps in producing maps that show potential sites for rainwater harvesting (Munyao, 2010). Using GIS in research helps in achieving multiple benefits such as integrating spatial and other kinds of information into a single system.

Besides, Geographic Information System offers a consistent framework for analyzing geographic data. Furthermore, it helps in putting maps and other kinds of spatial information into digital form. GIS allows the manipulation and display of geographic knowledge in new and exciting ways. Making connections between activities based on geographic proximity and looking at data geographically at the same time often suggest new insights and explanations to results. GIS is an efficient tool used in decision making in many fields of study (University of Durham Information Technology Service, 2006). For example, it is used in Spatial Multi-Criteria Evaluation when identifying sites suitable for water harvesting, and also used in rooftop rainwater harvesting.

Remote Sensing also refers to capturing data at distant locations "in situ" or without any physical contact between the phenomenon under study and the sensor (Tempfli, Kerle, Huurneman & Janssen, 2009). A remote sensing technique mainly provides data that is used in the GIS environment. Remote sensing and (GIS) are applied in various fields of study to perform different tasks defined by the user. GIS and Remote Sensing techniques have gained much popularity worldwide due to the numerous functions they perform, real-time data acquisition and sophisticated decision-making tools. GIS and Remote sensing help in the determination of areas suitable for water harvesting that supply water to supplement conventional water in areas facing water crisis (Isioye, Shebe, Momoh, & Bako, 2012). GIS has been recommended as a decision-making and problem-solving tool in RWH during decision-making process (Isioye, Shebe, Momoh, & Bako, 2012).

The use of these spatial technologies combine primary data sets from rainfall, runoff coefficient, soil, slope, land use/cover and the socio-economic characteristics of the area under consideration to access rainwater harvesting potential (Abdulla, 2011).

In a study conducted to assess rooftop rainwater harvesting in Pallavpuram area, 1036 polygons were captured as rooftops. The total area of rooftops was calculated to be 482,660.825 m^2. Given an average rainfall of 1000 mm, 0.7 average run-off coefficient of the rooftop, the total potential rainwater collected from rooftops was estimated to be 337,862,577.5 liters (Raj, 2011).

VanBeers, Bossilkov and Berkel (2008) did an evaluation on cost effectiveness and use of rainwater harvesting tanks for residential locations in Australia using GIS simulations. A comparison of the cost of operating rainwater tanks and alternative water sources such as building additional dams and desalination was then carried out. The findings of the study showed that rainwater harvesting is a cost-effective alternative for households in the area.

Sekar and Randhir (2007) developed a spatially explicit method to evaluate water harvesting in the Taunton River Watershed in Eastern Massachusetts, USA. The findings that emanated from the study confirmed that the application of spatial technology in water harvesting strategy could decrease runoff loss and enhance water supply.

In South Africa, a GIS-based decision-support system for rainwater harvesting was also built to assist decision-makers and stakeholders to indicate the suitability of RWH in any selected part of the country. The study demonstrated GIS based technology as an efficient tool in quantifying the potential impacts associated with its adoption at the catchment scale (Mwenge, Taigbenu, Sejamoholo, Lillie, & Boroto, 2009).

In the South Eastern United States, computer models were developed to simulate system performance for 2081 rain barrels and larger cisterns. The results showed that rain barrels were frequently depleted to meet gardens irrigation demands and overflowed during rainfall events (Matthew, William, & Hunt, 2010).

Kahinda et al (2008) offered a procedure that enables water managers to assess the appropriateness of rainwater harvesting for any given area by incorporating social and economic factors which earlier methodologies did not consider using GIS and Remote Sensing Techniques. The findings of the study acknowledged the relevant roles played by the inclusion of socio-economic factors in rainwater harvesting projects. According to the study, failure to incorporate these factors may lead to a subsequent failure in rainwater harvesting projects. Hence using a combination of physical, ecological and socio-economic factors help to develop maps of potential rainwater harvesting sites.

Factors that influence Adoption of Rainwater Harvesting Technologies

Shikur and Beshah (2013) identified socio-economic, physical, psychological and institutional constraints and opportunities that could determine the adoption of RWH technology with special emphasis on trapezoidal rainwater harvesting structures among farmers in Lanfuro Woreda, Ethiopia. An econometric model, binary logit model, was employed for determinants in adoption of RWH technology. The factors determined were labour availability in man equivalent, indigenous water harvesting experience of the household, farm size of the household head, total tropical livestock unit owned, distance of market from residence, sex of the household head, off-farm income of the household head, training in areas of RWH, perception of farmers towards security of land ownership and extension service in areas of RWH. The study revealed that ten variables were found significant at 5 percent to affect the adoption of RWH technology out of the twelve variables that were used in the model.

Alemayohu (2013) also designed and analysed factors that influence the adoption of Domestic Roof Water Harvesting (DRWH) practices using a binary logit model. The results of the study were based on data collected from a survey of 120 households which were selected using purposive and stratified sampling techniques. The results indicated that out of the total 11 explanatory variables used in a binary logit model, eight variables were significant at five percent to affect household decision to adopt DRWH practices. These were age, monthly income, perception towards quality, reliability of existing water supply, social responsibility, attitude towards importance of roof water harvesting, house ownership and affordability of the technology used.

McCloughan (2013) quantified the potential amount of rainwater that could be harvested from Western Kentucky University's main campus rooftops and also evaluated the potential environmental and economic value of such an initiative in light of the global water crisis. Roof areas and historic rainfall data were used to quantify the potential rainfall and it was found out that rainwater saves water by reducing dependence on potable water at the municipal level (McCloughan, 2013).

Nyamieri (2013) explored and analysed the implementation process, community's perceptions on rainwater harvesting technology and their influence on the adoption process by 'Uvati and Kawala' communities in Mwingi District, Kenya. The study targeted both adopters and non-adopters of rainwater harvesting technology. The results revealed that the rainwater harvesting technology was seen by the community members to be a good initiative in improving agricultural practices in periods of water scarcity. However, the technology's sustainability and widespread adoption seem unlikely, as its success was mainly directed and depended on the social factors. There, social factors should be incorporated into the planning and implementation stages of rainwater harvesting at the community level to ensure its sustainability.

Majority of the factors that influence the non-adoption process based on the community perceptions were found to be labour intensity of constructing the structures, lack of technical know-how, extensive training and dissemination of information to community members. Besides, the study also showed that the decision to adopt rainwater harvesting systems is dependent and influenced by the community's perception, and better understanding of their choices in making decisions (Nyamieri, 2013).

Kariuki (2011) examined socio-economic factors that influence adoption of rainwater harvesting technology in Kathiani and Kalawani communities, a division of Machakos district, Kenya. The socio-economic factors used were education of household head, gender, family size, income, roofing material, technology used, access to information, age, and group networking. The findings revealed that lack of finances played key role in hindering adoption of RWH. In addition, inadequate accessibility to information and poor technology also contributed to low adoption rate of RWH for domestic use. Roofing material was observed not to be a problem in the area but storage facilities and guttering were observed to hinder adoption of Rainwater Harvesting.

Ahmed, Onwonga, Mburu and Elhadi (2013) evaluated factors that influence the adoption of rainwater harvesting techniques among households (farmers) in Yatta district, Kenya using a binary logit regression model. The regression model showed that education level of household head, experience of water shortage, and awareness of water harvesting techniques and age of farmers have a significant and positive influence on adoption of water harvesting techniques. Most of the farmers were aware of a variety of water harvesting techniques, with roof water harvesting (45 percent) and dams (36.1 percent) being rated high, and were willing to adopt them within their local context.

Bhutani and Sehgal (2014) assessed the knowledge level of women regarding rainwater harvesting in Chowdhariwas, Balawas, Balsamand and Paniharchak communities, Hisar district of Haryana state. The study found that women’s knowledge regarding rainwater harvesting was high and majority of the respondents were now ready to adopt the technology in their farms as well as in their homes after knowing the benefits of the technology.

Domènech, March and Sauria (2013) explored the positive and adverse effects of rainwater and other different sources of water supply in two different societies of metropolitan Bacelona based on growth and de-growth of businesses using a multi-criteria evaluation approach. The technical analysis revealed that rainwater harvesting and reclaimed water reuse were the most preferred alternatives from a de-growth perspective.

Deressa, Hassan, Ringler, Alemu and Yesuf (2009) conducted an empirical study on adoption of rainwater harvesting among farmers of the Nile Basin. The findings showed that the level of education, gender, age, income, wealth of household, access to extension and credit, information on climate, farmer-to-farmer extension and number of relatives, influence farmers' adoption of RWH technologies. However, there is no consensus on factors that inspire or frustrate adoption of particular technologies and activities and therefore, a better understanding of these factors is required.

The Theory of Innovation Adoption and Rainwater Harvesting

The process of adopting new innovations has being studied for several decades, and one of the most widespread adoption models is described by Rogers in the book, *Diffusion of Innovations* (Sherry & Gibson, 2002). Several disciplines have made use of this model developed by Rogers as a theoretical framework. For instance Stuart (2000) cited several fields of studies that have extensively used this model like history, Geography, Political Science, Public Health, Communications, Economics, Technology, and Education. Rogers' theory has been widely used as a theoretical framework in the area of technology diffusion and adoption.

Rogers' diffusion of innovations theory is the most appropriate for exploring factors that influence household adoption decision of rainwater harvesting. Diffusion is the process by which an innovation is communicated through certain channels over time among members of a social system. Diffusion is a unique kind of communication concerned with the spread of messages that are perceived as new ideas. An innovation is an idea, practice, or object that is perceived as new by an individual, household or other unit of adoption. The distinctiveness of an innovation as perceived by the members of a social system, determine its rate of adoption.

Studies on diffusion also involve technological innovations and therefore the word "technology" and "innovation" are being used synonymously in his studies. Rogers' describes a technology as a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome (Rogers, 2003, p13). Also the technology is composed of two main components which are hardware and software. The hardware according to Rogers is the tool that embodies the technology in the form of a material or physical object, while the software component is "the information base for the tool" (Rogers, 2003, p.259) and most often than not it has a low level of observability, its rate of adoption is rather slow. Adoption is a decision of full use of an innovation as the best course of action available and rejection is a decision not to adopt an innovation (p.177). The four main elements in the diffusion of new ideas as identified by Rogers are;

1. The innovation;
2. Communication channels;

3. Time and
4. The social system

The innovation

Innovation as describe by Rogers refers to an idea, practice, or project that is perceived as new by an individual or other unit of adoption and may have being invented a long time ago. In adopting a particular innovation, Rogers identified uncertainty as an important obstacle that may lead to an individual or a social system to either adopt or reject an innovation. Therefore, in order to reduce the degree of uncertainty of adopting an innovation, individuals should be informed about its advantages and disadvantages to make them aware of all its consequences which can be further classified as desirable against undesirable, direct against indirect, and anticipated as opposed to unanticipated outcomes. The rate of adoption of an innovation is determined by five main characteristics. These are relative advantage, compatibility, complexity, trialability and observability.

Characteristics of Innovation and the rate of Adoption of Technology

Relative advantage

The relative advantage of an innovation is the degree to which an innovation is perceived as better than the idea it supersedes (p. 229). The degree of relative advantage is measured in economic terms, social prestige, convenience and satisfaction. The greater a household perceives relative advantage of rainwater harvesting, the greater the rate of adoption. The cost and social status motivation aspects of innovations are elements of relative advantage.

Innovation is further classified into two main types, preventive and non-preventive. Preventive innovation refers to a new idea that an individual adopts now in order to lower the likelihood of some unwanted future event. Preventive innovations frequently have a slow rate of adoption and are associated with a higher uncertain relative advantage whilst incremental innovations provide beneficial outcomes in a short period. To increase the rate of adopting innovations and to make relative advantage more effective may require either direct or indirect financial payment incentives to support individuals of a social system in adopting an innovation.

Compatibility

Another motivation factor in the diffusion process is the compatibility attribute. This is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters (p.15). A practice or an idea that is incompatible with the values and norms of social system will not be adopted as rapidly as an innovation that is compatible.

Complexity

Complexity refers to the extent to which an innovation is perceived as difficult to understand and use by a social system. Some innovations are easily understood by members of the social system whilst complicated ones are adopted but very slowly. Rainwater harvesting technologies that are simpler to understand are adopted more rapidly than technologies that are very complex to understand and adopt. In view of this, the excessive complexity of a rainwater harvesting technology hinders the rate of its adoption. The complexity of the system depends on the technology used. For instance, rooftop rainwater harvesting technology is very simple and does not require much complex design as compared to other technologies on pervious surfaces.

Trialability

Trialability is the ability of potential adopters of an innovation to experiment it within a short period. Rainwater harvesting technologies that can be tried on the installment plan will generally be adopted more quickly than innovations that are not divisible. An innovation (rainwater harvesting technology) that is trialable represents less uncertainty to a household who is considering it for adoption. Hence the more an innovation is tried by a social group, the faster its adoption rate increases.

Observability

This considers the extent to which the anticipated outcome of an innovation is visible to others in the social system. The easier it is for household to see the results of an innovation, the more likely they are to adopt. This visibility stimulates peer discussion (Parisot, 1997) of a new idea as individuals and household of an adopter often request innovation evaluation information about it.

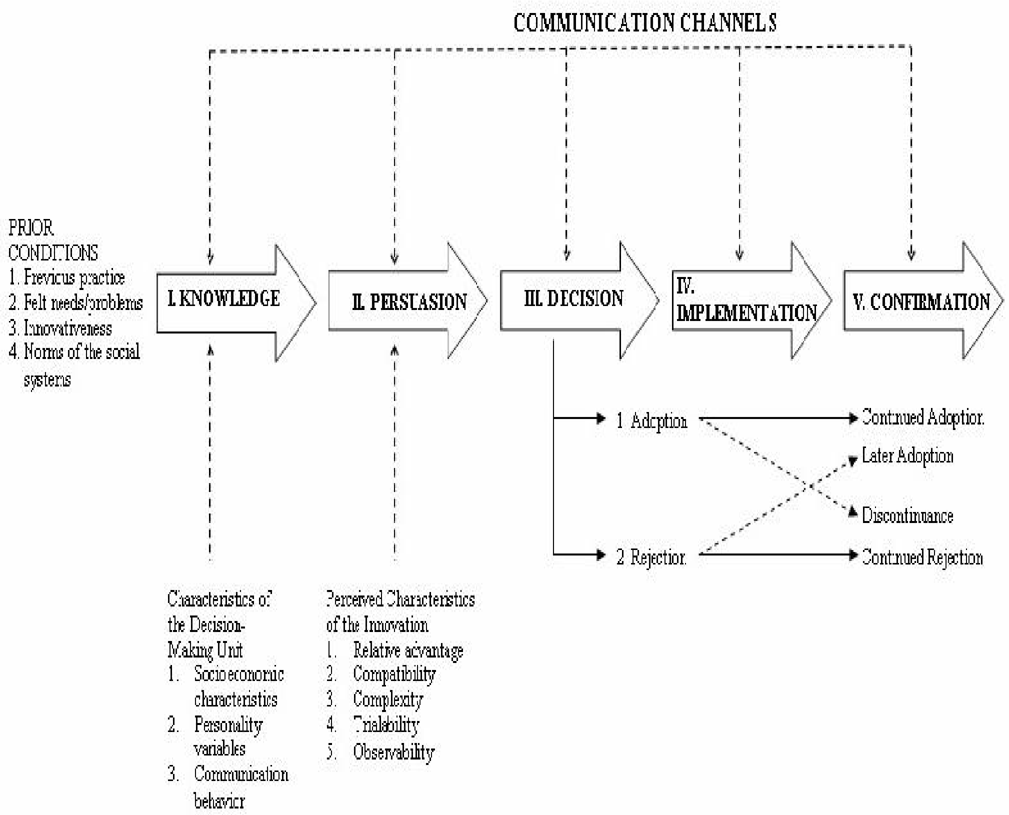
The communication channels

Communication is the process by which people who take part in an activity create and share information with one another in order to reach a common understanding. A communication channel is the means by which information is passed from one individual to another. The use of mass media as a medium of disseminating information is more effective in creating knowledge or innovations. Interpersonal channels are more effective in changing attitudes toward a new idea and influence the decision to adopt or not to adopt rainwater harvesting technology by household. Household evaluate an innovation (rainwater harvesting) not on the basis of scientific research by expects, but through the subjective evaluations of closer-neighbours who have adopted the innovation.

Interpersonal channels may have a characteristic of *homophily*, or the extents to which individuals who interact with one another have similar characteristics such as beliefs, education, socio-economic status, and others. The diffusion of innovation requires at least some degree of heterophily (the degree to which individuals who interact are dissimilar in certain features).

Time

In the innovation-diffusion process, adopter categorisation and rate of adoption of a given technology all include a time dimension which makes time a relevant factor. The time dimension in the decision making process by household as to adopt or not adopt rainwater harvesting technologies occurs in three forms. First, the household decision process is the process begins from knowledge stage to a decision to adopt or not adopt, implementation of the new idea which in this case is the rainwater harvesting and finally to the confirmation stage of such decision taken. Household seeks information at different stages in the order to minimise the uncertainty of negative consequences in the outcome of such decisions. Five main steps were identified in the innovation-decision and these are knowledge, persuasion,


COMMUNICATION CHANNELS
PRIOR CONDITIONS
1. Previous practice
2. Felt needs/problems
3. Innovativeness
4. Norms of the social systems
I. KNOWLEDGE
II. PERSUASION
III. DECISION
IV. IMPLEMENTATION
V. CONFIRMATION
1 Adoption
2 Rejection
Continued Adoption
Later Adoption
Discontinuance
Continued Rejection
Characteristics of the Decision-Making Unit
1. Socioeconomic characteristics
2. Personality variables
3. Communication behavior
Perceived Characteristics of the Innovation
1. Relative advantage
2. Compatibility
3. Complexity
4. Trialability
5. Observability

The persuasion stage

The persuasion stage occurs when the individual has a negative or positive attitude toward the innovation. A household is persuaded to either be part of a favourable or unfavourable attitude toward rainwater harvesting.

Decision

This follows the persuasion stage and at this period, a household makes a final decision to either adopt or reject rainwater harvesting. In this stage, as adoption refers to full use of an innovation as the best course of action available, rejection means "not to adopt an innovation" (Rogers, 2003, p. 177). Rogers expressed two types of rejection which are active rejection and passive rejection. In an active rejection situation, an individual tries an innovation and thinks about adopting it, but later he or she decides not to adopt it. A discontinuance decision, which is to reject an innovation after adopting it earlier, may be considered as an active type of rejection. In a passive rejection (or non-adoption) position, the individual does not think about adopting the innovation at all.

Implementation stage

This refers to the period in which household puts the innovation (rainwater harvesting) into practice or use.

Confirmation

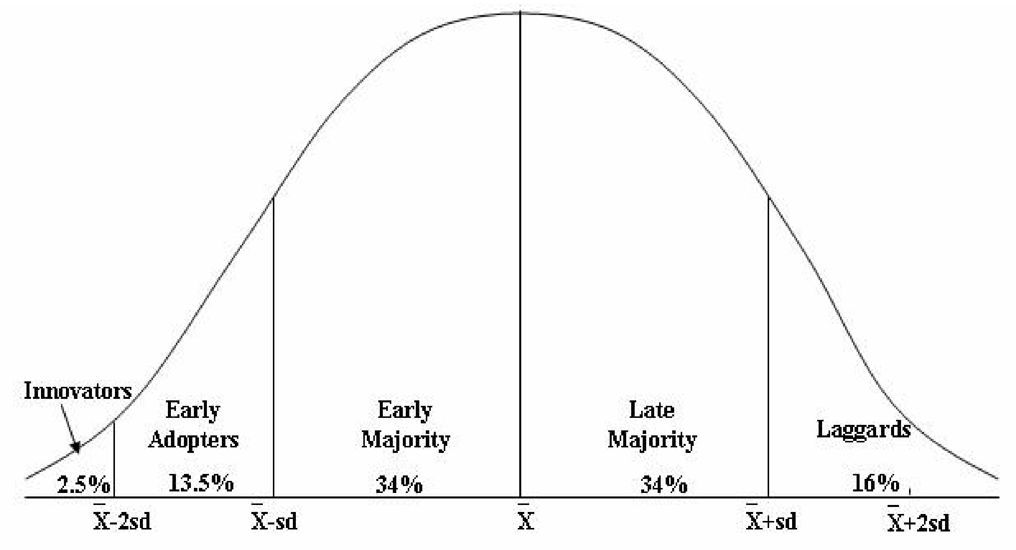
During this period, a household evaluates the outcome of the decision taken at the implementation stage with support. This decision can be reversed if the individual is exposed to conflicting messages about the innovation. Thus, attitudes become more crucial at the confirmation stage. Depending on the support for adoption of the innovation and the attitude of the individual, later adoption or discontinuance happens during this stage.

Discontinuance may occur during this stage in two ways. First, the individual rejects the innovation in order to adopt a better innovation. This type of discontinuance decision is called replacement discontinuance. The other type of discontinuance decision is disenchantment discontinuance. In the latter, the individual rejects the innovation because he or she is not satisfied with its performance. Another reason for this type of discontinuance decision may be that the innovation does not meet the needs of the individual. So, it does not provide a perceived relative advantage, which is the first attribute of innovation and affects the rate of adoption.

Second, time dimension is involved in diffusion innovation based on innovativeness of a household or other unit of adoption. Innovativeness in this context refers to the extent to which an individual or a household is relatively earlier in adopting rainwater harvesting technology than other members of a social system. A household innovativeness as an adopter of rainwater harvesting technology is classified into five groups. These are;

1. Innovators
2. Early adopters
3. Early majority
4. Late majority and
5. Laggards

The third way in which time dimension is relevant in the diffusion innovation process is the rate of adoption. The rate of adoption refers to the relative speed with which an innovation is adopted by members of a social



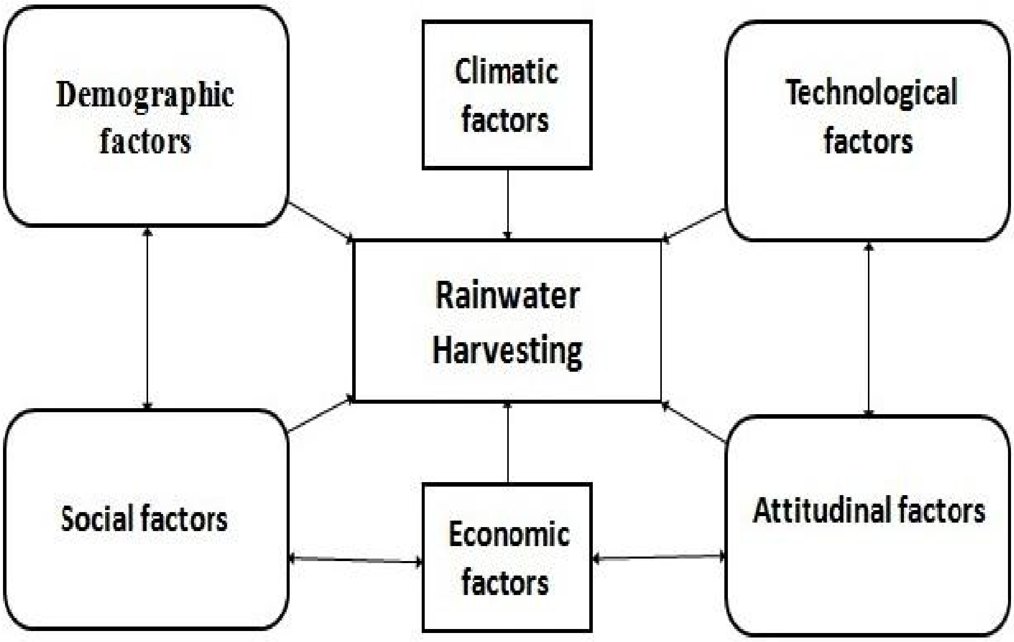
Innovators
Early Adopters
Early Majority
Late Majority
Laggards
2.5%
13.5%
34%
34%
16%
$\bar{X}$-2sd
$\bar{X}$-sd
$\bar{X}$
$\bar{X}$+sd
$\bar{X}$+2sd

may be household, individuals, organisations and etc. Diffusion of innovation occurs in the social system and is thus influenced by the social structure which refers to the pattern of arrangements of units in a social system. The nature of the social system influences individuals' innovativeness, which form the basis for categorising adopters of a particular technology.

The Conceptual Framework

Conceptual framework for this study was constructed based on the concept of rainwater harvesting and the relationship that exist between the components of water harvesting. Similar studies on rainwater harvesting were (Nyamieri, 2013) also taken into consideration in developing this conceptual framework (Figure 4). The framework looks at the concept of rainwater harvesting and it delves into the determinants of rainwater harvesting. It also explores the link between the determinants of water harvesting. The factors that influence rainwater harvesting as depicted in the framework in Figure 4 are the demographic , climatic, technological, attitudinal, economic and social factors, scale of operation (the extent of water harvesting), storage of rainwater, alternative sources of water supply, physical factors (rainfall pattern), economic factors, attitudinal factors, socio- demographic and technological factors.

The socio-demographic factors refer to the characteristics of individuals and households as these may have influence on their decisions to engage in rainwater harvesting. Among these factors include gender (sex), age, marital status, religion, household size, educational level that play significant roles in rainwater harvesting (Nigigi, 2003).


Demographic factors
Climatic factors
Technological factors
Rainwater Harvesting
Social factors
Economic factors
Attitudinal factors

accounts for the use of rooftop is that the technology is quite simpler to pervious technology like ground surfaces.

Attitudinal factors in the framework deal with issues such as the attitude of people towards rainwater, their perceptions about rainwater quality and their willingness to accept the use of rainwater (Jeffrey & Gearey, 2006).

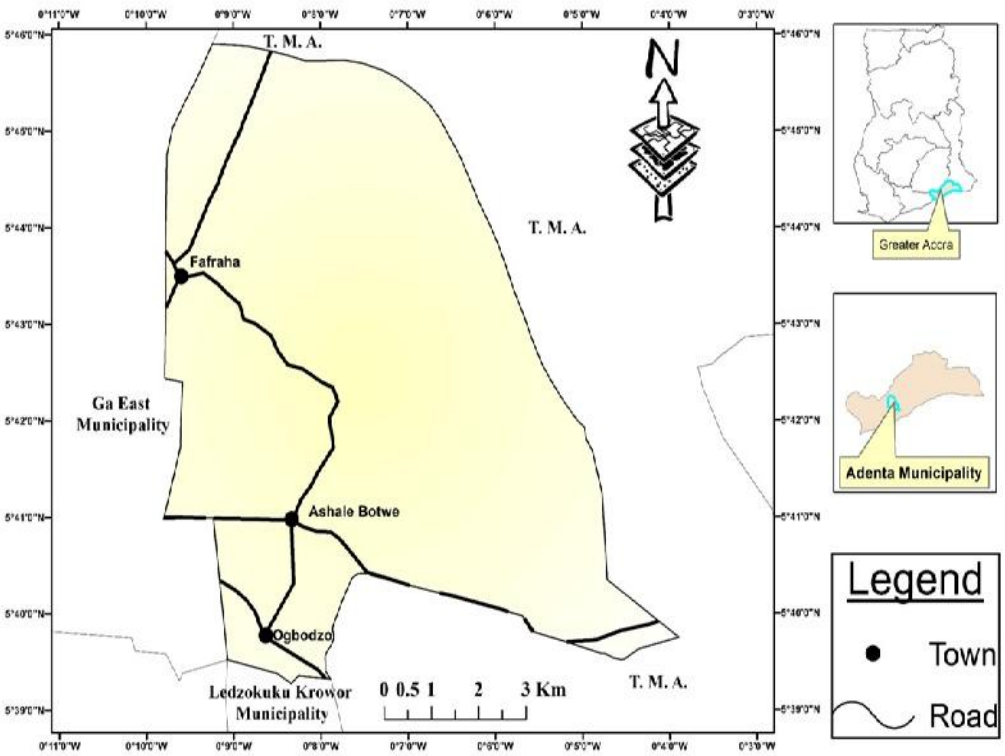
Social factors also consider the social and cultural background of households in rainwater harvesting. These factors include the kind of social groups or associations that the individual or groups belong because they play roles in households' decisions toward accepting and using rainwater harvesting technology.

Economic factors entail the economic background of households which include their occupations, income level, the type of houses people live in as well as the type of roofing materials used, their ability to afford the cost of materials required to install harvesting system, cost of regular maintenance and the availability of space to store water all affect rainwater harvesting (Petrucci et al, 2012).

The interactions between the aforementioned factors in the framework all aid in assessing the potential of rainwater harvesting in a given area. Therefore, the framework serves as a guide that informed the direction of the study from the methodology to the findings and is therefore not exact but subject to modification.

Summary

The chapter began with review of literature and a conceptual framework that informed the study. The concept of rainwater harvesting was also covered. Generally, literature was reviewed under specific themes which include the extent of rainwater harvesting; rainwater storage; the quality of rainwater; potential rainwater that can be harvested using rooftops; and factor likely to influence households decisions to adopt rainwater harvesting technology. The chapter also delved into discussing the theory of innovation adoption and finally concluded with the conceptual framework for domestic rainwater harvesting.


T. M. A.
T. M. A.
T. M. A.
Fafraha
Ga East Municipality
Ashale Botwe
Ogbodzo
Ledzokuku Krowor Municipality
0 0.5 1 2 3 Km
Greater Accra
Adenta Municipality
Legend
Town
Road

Location and size

The Adentan Municipality lies about 10 Kilometres to the North East of Accra, which is specifically located on latitude 5^{o} 43'North and longitude 0^{o} 09'West. It shares boundaries with Tema Metropolitan Assembly (TMA) in the East, Ga East Municipal Assembly in the West, Oyibi Township (part of the TMA) in the north, and Madina, a suburb of Ga East Municipality in the south (Korley, 2011). The Adentan Municipal Assembly was created out of the Tema Metropolitan Assembly (TMA). An Act of Parliament (Act 462, LI1888) on the 29th February, 2008 created Adentan Municipal Assembly (Adentan Municiapal Assembly [ADMA], 2014). The land area of the Municipality is about 85 sq km (33 sq miles). Adentan Municipal area also serves as a nodal point where the main Accra/Aburi/Koforidua and Accra/Dodowa trunk roads pass.

Climate

The Municipality lies in the coastal savannah zone of Ghana and has a dry equatorial climate. Temperatures are generally high throughout the year. The annual average temperature ranges between 25° C and 30° C in the major rainy season and 34° C and 40° C in the minor season. The high temperatures warm up the air which rises to condense contributing to the type of precipitation called conventional rainfall for the area. March to April is usually the hottest period with temperatures reaching 32° C during the day and 27° C at night. Cooler temperatures occur from May to September with a high of 27-29° C during the day and 22-24° C in the night (Korley, 2011).

Rainfall

The Municipality experiences two types of rainy seasons with average annual rainfall ranging between 730 mm to 790 mm. The first or major rainy season starts from April to July whilst the second or minor rainy season starts from September to November each year. The bi-modal rainfall pattern provides a suitable environment for agricultural activities in most months of the year as inhabitants are able to cultivate and harvest different types of crops.

Relief rainfall in the Municipality occurs because of the presence of the Akuapim range that serves as a natural border for the community. This range serves as an impediment for the South-Easterlies moisture bearing winds from the sea which forces this warm air to rise and condense into rain bearing clouds and hence producing copious rainfall in the municipality. Humidity varies from 60 percent to 80 percent or more in the wet season to less than 30 percent in the dry season.

Vegetation

The rainfall pattern and the terrain of Adentan Municipality have influenced the vegetative cover of the environment. The southern part is covered by savannah vegetation with dispersed nim trees. The northern part has savannah semi-rain forest with deciduous trees.

Soil

The soils in Adentan are highly elastic during the wet season and become hard and compact when dry. This hinders crop production during the dry season. Basically, soils found in the area are brownish grey and are underlain by a hard porous gristly loam in many areas.

Geology

Adentan Municipality is underlain with Precambrian rocks of the Dahomeyan formation. The dominant rocks found in the northern part are metamorphic rocks that consist of granite and gneiss while sedimentary rocks dominate at the Southern, Western and Eastern parts of the Municipality. The presence of the rocks promotes stone quarry and sand winning activities.

Natural Environment

Adentan abounds in several natural resources of which prominent among them are the Nugbete River in Nmaidjor and the Ogbojo stream. These resources have being polluted with poor waste management practices. Among some of the common wastes are plastic materials, used papers and polythene bags. Literature suggests that the Ogbojo stream has the tendency of overflowing its banks during the rainy season making it difficult for residents to access the Ogbojo market and other socio-economic facilities such schools at its other side (Korley, 2011).

Population

The Adentan Municipal area has a population of Seventy-Eight Thousand, Two Hundred and Fifteen (78,215). Out of this, Thirty-Nine Thousand, Three hundred and Sixty-Six (39,366) are males and Thirty-Eight Thousand, Eight Hundred and Forty Nine (38,849) are females with a growth rate of 2.6 percent (Ghana Statistical Service, 2010).

Economic Activities

About 30 percent of the labour force is engaged in crop farming, fishing, food processing, livestock and agro-forestry. Among some of the major crops grown in the area include onion, pepper, tomatoes, okra, leafy vegetables, maize, plantain, legumes, watermelon and mushroom. In the case of livestock production, about 80 farmers are involved in producing Grass Cutter. The average holding is about 10 but some farmers have as high as 300 animals. Most of these farmers are assisted technically by MOFA staff. CSIR staffs also assist by providing research information to farmers (Ministry of Food and Agriculture, 2014).

Water delivery system

Adentan hardly gets potable pipe borne water and most of the residents resort to poly tanks, and concrete built tanks to store water supplied by water vendors, bole holes and wells. The residents also harvest rainwater during the rainy seasons. Potable water in Adentan Municipality becomes an essential commodity during the dry season (Adentan Municiapal Assembly [ADMA], 2014). This makes those supplying water in lorry tankers to charge exorbitant prices. The quality of the water supplied by these tanker operators is not guaranteed and has health implications. Until the recent installation of the new water treatment plant with a capacity of 186,000m^3 per day at Kpong which now serves the eastern part of Accra including Adentan, residents get their water supply from a 40,000m^3 reservoir constructed at Oyibi which was funded by a grant offered by the Chinese government. Despite all these efforts to improve the water situation, water is supplied twice a week on Fridays and

Saturdays only. This does not cover the entire municipality but limited to certain parts. For instance, interview with some key informants in Adentan village revealed that they have never being supplied with water. The Municipal Assembly has also dug boreholes across the Municipality to augment other sources of water supply (Adentan Municiapal Assembly [ADMA], 2014).

Research design

Research design can be thought of as the logic or master plan of a research that throws light on how the study is to be conducted (Creswell, 2007). The main function of a research design is to ensure that enough evidence has being obtained that will enable one to effectively address the research problem logically and as unambiguously as possible (Labaree, 2013). It gives directions from the underlying philosophical assumptions to data collection (Yin, 2003). In view of this, this study adopted a descriptive study design because it provides adequate information concerning the current status of the phenomena and to describe what exists (Shuttleworth, 2008). Descriptive research design elaborates what is really happening on the ground in a completely natural and unchanged natural environment. For instance, in human research, a descriptive study can provide information about the naturally occurring health status, behaviour, attitudes or other characteristics of a particular group.

Descriptive design is usually the best method for collecting data that demonstrates associations or relationships between things and describes a particular phenomenon in its natural state (Sarantakos, 2005). This is usually done through interactions with the participants, questionnaires or interviews to collect the necessary information. It involves the use of both qualitative and quantitative techniques to describe, record, analyse and interpret conditions that exist (Jackson, 2009). It is often used as a pre-cursor to more quantitative research designs with the general overview giving some valuable pointers as to what variables are worth testing quantitatively (Patten, 2005). In qualitative techniques, it serves as a useful tool in developing a more focused study and yield rich data that can lead to important recommendations in practice. Descriptive research designs help provide answers to the questions of *who*, *what*, *when*, *where*, and *how*, associated with a particular research problem.

Aside the numerous benefits associated with the use of descriptive study design, it has some disadvantages of which some are outlined below. First, the results from a descriptive research cannot be used to discover a definitive answer. Second, in the case of descriptive studies where research is not heavily dependent on instrumentation for measurement and observation as opposed to quantitative methods, results cannot be replicated (Grimes & Schulz, 2002). The cross sectional design was specifically used in the study because it deals with a cross section of a population at a particular period in order to create some level of representativeness (Bryman, 2008).

The study also adopted the mixed method approach or qualitative and quantitative. Quantitative research is defined as an inquiry into a social or human problem, based on testing a hypothesis or theory composed of variables, measured with numbers, and analysed with statistical procedure to determine whether the hypothesis or theory holds true (Creswell, 2003). The most widely used method in social science is survey technique and is the most relevant to this study (Shields & Patricia, 2006). It comprises the use of questionnaires or interviews to gather large volumes of data. The most common forms of this technique are mail, personal and telephone survey (Rubin & Babbie, 2009). This method was adopted because it allows high flexibility in the questioning process and yields a higher response rate. Besides, interviewers have control of the interviewing situation and also there is the possibility of collecting supplementary information which may not be in the data collection instrument (Marans & Edelstein, 2010).

Aside these benefits derived from the use of this method, it also has some flaws. There is lack of anonymity which occurs as a result of hesitance to disclose personal data, an element of bias on the side of potential interviewers and it is time consuming. Despite all these shortfalls, it was still used because of the high flexibility in the data collection process (Rubin & Babbie, 2009).

Qualitative research was also used in this study because it facilitates an in-depth study as well as detailed information in studies which involve a smaller number of people. More so, according to Flick (2009), qualitative studies offer a better understanding of the topic under study (Stebbins, 2001). Despite the benefits offered by qualitative studies, it also has some few drawbacks. It requires a greater time for data collection and interpretation which in some instances may lead to personal bias or lack objectivity in findings (Babbie, 2005; Flick, 2009).

The roots of mixed methods are typically traced to the multi-trait, multi-method approach of Campbell and Fiske (Teddlie & Tashakkori, 2009).

Triangulation or mixed methods are used in testing the agreement of findings obtained from different measuring instruments, clarifying and building on the results of one method with another method, and demonstrating how the results from one method can impact subsequent methods or inferences drawn from the results (Maruna, 2010). This method involves the comparison of data relating to the same issue or phenomenon of investigation but from different perspectives or from different methods of collection (Greene, 2007). A typical example is making a comparison of data from different stages of research; comparison of data from different sets of participants; or comparison of data from different tests that purport to measure the same variable. Data is therefore crosschecked in order to confirm a hypothesis or research question (Amaratunga, Baldry, Sarshar, & Newton, 2002). Triangulation of data can show up disjunctions in the research results, as well as provide additional insights (Wheeldon, 2010).

In recognising the view that all methods have limitations, several biases inherent in any single method could neutralise or cancel the biases of other methods (Tashakkori, 2009). Hence the ultimate reason for using triangulation data sources was to serve as a means of seeking convergence across qualitative and quantitative methods that was used in this study (Creswell, 2007).

The target population

The main target population chosen for the study was household heads within the Adentan Municipality. The total number of household heads in the municipality based on the 2010 Population and Housing Census Regional Analytical Report was estimated to be 20847.

Sample size determination

The sample size for this study was estimated based on the mathematical formula developed by Fisher et al (1998), $\boldsymbol{n} = \frac{z^2pq}{d^2}$;

Where n = the desired sample size (when the population is greater than 10,000), z = the standard normal deviation, usually set at 1.96 (or more simply 2.0) which corresponds to 95 percent confidence level, p = the proportion in the target population estimated to have particular characteristics and is given as 0.85, q =1.0-p, d = degree of accuracy desired, usually set at 0.05. Using a target household head population of 20,478 and substituting the values into the formula,

$$\boldsymbol{n} = \frac{(1.96)^2(0.85)(0.15)}{(0.05)^2};$$

n = 196

Sampling Procedure

A combination of Probability and non-probability sampling techniques were used in the study. Specifically, stratified random sampling was used to select household heads while key informants were selected based on purposive sampling. First, a stratified random sampling method was adopted to ensure that the sample size selected spread across the entire study area mainly because of the large spatial extent of the municipality. Stratified random sampling is used in instances where the target population to be sampled lacks adequate homogeneity but consist of several sub-populations (Adegoke, Adedayo, Aderinto, & Yesufu, 2013; Patten, 2005).

A multi-stage sampling method was adopted in the study. First the study area was stratified based on income level as high, middle and low. There are 20847 household heads based on the 2010 Population and Housing Census Regional Analytical Report (Ghana Statistical Service, 2010). Out of this total, male household heads constituted 71.5 percent whilst that of female household heads was 28.5 percent (Ghana Statistical Service, 2013). Secondly, households within each income level were again stratified according to adoption status (that is, adopter and non-adopter). This was done in order to generate a reasonable proportion of both households who are adopters and non-adopters and to avoid the probability of respondents being only of adopters or non-adopters. This was done by obtaining a list of adopters and non-adopters in the study area through extensive transect walk and field observation. The list of both adopters and non-adopters were randomly sampled using a desktop analysis and the sample size for the study was shared equally among adopters and non-adopters households.

A number of other key informants were chosen purposively and interviewed for the study because they were people who are noted to have useful information that could supplement data obtained from the household heads. According to Bernard (2006), in purposive sampling, you decide the purpose you want informants to serve, before choosing informants for a particular study. It can also be useful in situations where you need to reach targeted sample quickly and where the sampling for proportionality is not the primary concern (Trochim, 2000). Therefore, key informants each from the

Ministry of Water Resources Works and Housing, Adentan Municipal Assembly, Community Water and Sanitation Agency and Ghana water Company Limited were interviewed.

Data and sources

Primary and secondary sources of data were used in the study to achieve the objectives. These were further classified into spatial (geographic) and non-spatial data (non-geographic). These two main data types are briefly explain in the following sections.

Spatial data and sources

The primary data was obtained with the aid of a GPS device through field verification and observation. Secondary spatial data used were monthly rainfall data and buildings layers digitised from an orthophoto satellite image of the study area. Rainfall data was obtained from the Ghana Meteorological Agency in Accra and the building layers was obtained from the Survey and Mapping Division in Accra. The building layer was extracted from a 2003 and 2004 aerial photograph. The scale of the building layers was 1:2500 while the spatial extent of the orthophoto satellite image was 1: 10000.

Non-spatial data and sources

To be able to meet all the research objectives non-spatial primary data was obtained from the fieldwork and this included data on average annual household water demand, the extent of rainwater harvesting in the municipality, social, economic, cultural, and technological factors that explained household's decision making regarding the adoption or non-adoption of rainwater harvesting technology.

The secondary data was obtained from relevant sources such as the Demographic and Health Survey Reports from Ghana Statistical Service, the Ministry of Water Resources Works and Housing, Ghana Water Company limited, Community Water and Sanitation Agency, Planning Department of the Adentan Municipal Assembly and published and unpublished documents or literature on rainwater harvesting.

Data collection instruments

Non-spatial data

Survey is one of the most widely used methods in the social sciences to provide representative samples of the study area. It serves as an efficient and effective means of studying far greater numbers of variables than possible with experimental approaches. In the survey research, information is elicited from respondents through questionnaires or structured interviews for data collection with the aim of generalising from a sample to a population (Creswell, 2007; Creswell, 2003). The survey research method was adopted to provide a quantitative description of trends, attitudes, or opinions of the population by studying a sample of the population (Creswell, 2003).

A questionnaire was designed to generate data and the items consisted of both closed-ended and open-ended questions. In the case of the former, respondents were limited to choose from a given set of predefined responses whilst in the latter or the open-ended situation respondents were given the chance to provide their own responses without any restrictions. Open-ended questions allow for a greater variety of responses from participants but are difficult to analyse statistically because the data must be coded or reduced in some manner. Closed-ended questions are easy to analyse statistically but seriously limit the responses that participants can give (Jackson, 2009).

A questionnaire was used because it is considered as a resourceful and effective instrument in sampling a large number of household heads scattered over an entire municipality. Most of the variables were measured using the Likert scale since it provides an acceptable way of eliciting the strength of opinions using numbers to represent implicit meanings (Assaf & Al-Hejji, 2006; Carmichael, Edwards & Holt, 2007). Examples of the Likert scale used in the questionnaire to solicit the views of Household heads on the extent of rainwater harvesting and the factors that influence the adoption decisions were Strongly Agree, Agree, Undecided, Disagree, and Strongly Disagree.

Key informants selected were also interviewed on issues similar to that of the household heads to complement the information obtained from the household heads. The nature of the study deemed it relevant to also observe existing rainwater harvesting technologies being used by household heads who really harvest rainwater.

Spatial (Geographic data)

Spatial data was collected using Remote Sensing and Geographic Information Systems Techniques. ArcGIS 10.1 software manufactured by Environmental Systems Research Institute (ESRI) in 2012 was used. Other software like Google map developed by Google was used to update the data whist Quantum GIS Dufour 2.0 software was used to convert data from one format to another.

Data collection/ Fieldwork

Non spatial (Household data)

Reconnaissance study was done in order to have a fair idea and be familiar with the study area based on the income stratification. The research instruments were pretested in other areas with characteristics similar to Adentan Municipality to ensure their effectiveness before the actual fieldwork was embarked on in the Adentan Municipality. During the data collection, questionnaires were administered to household heads to provide the necessary responses needed. In the case of households heads that could neither read nor write, the necessary assistance was given to them to complete the questionnaire by reading and interpreting the questionnaires to them. A period of three weeks was used to administer the questionnaires, interview schedules and observational studies. The data collection began on 13th March, 2015 and ended on 2nd April, 2015 from 8:30 AM to 4: 30 PM each day.

Spatial (Geographic) data

Capturing of spatial data for water harvesting

Estimating the amount of water that can be generated from building required the capturing of spatial data. In view of this, all roofs of buildings were considered using census data and included in the study. A vector overlay analysis using the clip function was used to extract the study area by reducing the spatial extent of the building layers obtained from Survey and Mapping

Division by creating an area of interest. This was done using ArcGIS 10.1 and Erdas Imagine 2013. After this was done, all rooftops in the Municipality were captured as polygons using the editing tool in ArcGIS software and stored in a geodatabase.

The data captured and stored in a geodatabase was further converted into a KML format using Quantum GIS Duffour software and exported to Google Earth for further updates since the aerial photograph of the study area initially used was old and there was the need to incorporate newly built houses that were not in place at the time the aerial photograph was taken. The outputs vector layers which were in Keyhole Markup Language format (KML) were converted into feature classes in ESRI geodatabase formats. The reason for the conversion was because of the limitations Google Earth has with analysis of geographic features. In order to overcome this limitation, a sophisticated GIS software ESRI Arc GIS version 10.1 was used for further analysis.

Field verification was also done for some particular well known buildings whose roofs were captured. Rainfall data used for the analysis was obtained from the Ghana Meteorological Agency in Accra from 1982 to 2012.

The Fieldwork challenges

There are so many challenges associated with rooftop water harvesting especially during the data capturing process. One of these occurs when capturing data in areas where buildings are unplanned or built haphazardly, for instance congested areas like slums. In this study, areas that were unplanned or have dilapidated buildings or structures, rooftop rainwater harvesting was considered to be unsuitable and therefore was ignored. Only proper rooftops were captured. Rooftops of buildings in the municipality that are clustered with housing plots in continuity without any spaces left in between houses were captured in the form of one big polygon.

Another major challenged during the fieldwork was that some of the respondents were not willing to take part in the study. According to them, researchers have being obtaining data from them but they do not see any changes in their community and felt it was unnecessary to take part in subsequent studies. However, when the motive of the study was well explained to them and the need to take part in the study, most of them finally decided to answer the questions.

Household heads who could neither read nor write found it difficult to give the sizes of their rainwater storage facilities. This problem was resolved by assisting them to identify the storage sizes of poly tanks and using other forms of relative measurements.

There was a problem of getting access to houses that were in an enclosed environment (gated houses) because most of their gates were locked making it difficult to get access to the heads in such houses. However, since the study area is relatively large, houses for whose accessibility was a problem were ignored.

Lastly, during the preliminary stage of the fieldwork, there was the need to identify households with rainwater harvesting facilities in order to avoid the probability of involving only those without harvesting facilities. This at the initial stage was very tiresome. This situation became very easy when many field assistants were deplored to the field by dividing the area into sections with a number of field assistants to each section.

Data Analysis and Presentation

Non-Spatial data (Household data)

This study used both qualitative and quantitative methods of data analyses as aforementioned in the study design. Data collected from the fieldwork was cleaned, coded, and checked for consistency before keying into the SPSS software for further processing and analysis based on the study objectives. Questions and statements measured on a five point Likert scale were eventually transformed into a three point Likert scale for ease of analysis. Descriptive and inferential statistics such as frequency tables, and charts were generated and summarised according to the objectives of the study. Information from in-depth interviews was used to support or buttress some of the findings from the questionnaires (household data).

In evaluating the factors that influence household's decision to adopt or not to adopt rainwater harvesting technology in the municipality, a suitable econometric model was used in addition to descriptive statistics to explore the association between the dependent and independent variables. Measures of central tendencies, dispersion, minimum and maximum values of independent variables were indicated. The result obtained was used as an indicator of the relationship between dependent and independent variables. Specifically, the binary logit regression model was used to analyse factors affecting household decision to adopt rainwater harvesting practices.

The use of Binary Logistic Model

The decisions taken by households as to whether they will adopt or participate in rainwater harvesting has two main responses or dichotomous variables which could be 'yes' or 'no' (Hosmer & Lemeshow, 2000). Although a lot of statistical models or formulas could have being used to explore the relationship between the factors that affect household's decision to adopt the technology of rainwater harvesting or not to adopt. The logistic regression model was adopted because it has advantages over other similar econometric models in the analysis of dichotomous variable.

First, this model from a mechanical point of view is very flexible and easy to understand. Second, the model provides a meaningful interpretation that makes it simpler than probit model (Baiyegunhi, 2015). The logit model was chosen because the properties of estimation procedures are more desirable than those associated with the choice of a uniform distribution (Pindyck & Rubinfeld 1998). In the logit regression model, parameters are determined through maximum likelihood estimation (MLE) procedure (Ahmed et al, 2013). In fact, considering these few advantages over probit model, the binary logistic regression model was used for analysing this particular objective of the study that is to determine factors that influence the adoption of rainwater harvesting technologies.

Following Shikur and Beshah (2013) and (Ahmed et al, 2013), the binary logistic distribution function for analysing households' decisions of adoption of Rainwater harvesting technology can be defined as:

$$PB_iB = \frac{1}{1 + e^{-zi}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where; PB_iB is the probability of being willing to participate for the iP^{th} household and ZB_iB is a function of m independent (explanatory) variables (XB_iB), and expressed as

$$ZB_{iB} =$$

$$\beta B_{0B} + \beta B_{1B} XB_{1B} + \beta B_{2B} XB_{2B} + \ldots \beta B_{mB} XB_{mB} \ldots\ldots\ldots\ldots\ldots (2)$$

Where; βB_{0B} is the intercept and βB_{iB} are the gradient parameters in the model and indicate how the log-odds in favour of households decisions to adopt rainwater harvesting technology change with the explanatory variables (XB_iB). Also, in order for an easy interpretation of the coefficient of the binomial distribution with a conditional probability of p_i, the binary logistic model is rewritten in terms of the odds and log of the odds. Therefore the odds used in the model is defined as the ratio of the probability that a particular household will adopt rainwater harvesting (p_i) to the probability that a household will not adopt $(1 - p_i)$.

But

$$[1 - p_i] = \frac{1}{1 + e^{z(i)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Therefore,

$$\left[\frac{p_i}{1 - p_i}\right] = \frac{1 + e^{z(i)}}{1 + e^{-z(i)}} = e^{z(i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

And

$$\frac{p_{(i)}}{1-p_{(i)}} = \frac{1+e^{z(i)}}{1+e^{-z(i)}} = e^{\beta 0} + \sum_{i-1}^{m} \beta_i Y_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Taking the natural logarithms of the odds ratio of equation (5) gives the binary logit model in equation (6) indicated below

$$In\left[\frac{p_{(i)}}{1-p_{(i)}}\right] = In\left[e^{\beta 0} + \sum_{i-1}^{m} \beta_i X_i\right] = Z_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

From equation (6), if the disturbance term U_i is taken into account the logit model then becomes

$$Z_{(i)} = B_0 + \sum \beta_i X_i + U_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Finally, equation (7) is the econometric model used in the study to determine factors that influence households' decisions to adopt Rainwater harvesting technology in the Adentan municipality. Therefore, the factors; age of household head, sex, educational level, religion of household heads, household size, awareness of water harvesting techniques, willingness to accept, source of income, roofing material, availability of alternative sources of water supply, household ownership, technological know-how, rainfall pattern (high or low), availability of space, the use of simple technology, government support, size of storage facility, skilled labour, experience on water shortage, encouragement of household, rainwater quality and among others were modelled in order to explain their influence on households adoption of water harvesting techniques.

Definition of Variables and Working Assumptions of Factors that Influence Households Decision to Adopt Rooftop Rainwater Harvesting Technology

The last objective of the study was to identify factors that influence household decisions to adopt rooftop rain water harvesting technology in the study area. This part talks about technological, attitudinal, socio-demographic, economic, climatic and other factors that affect households' decision to adopt or not to adopt rooftop rainwater harvesting practices in Adentan Municipality. It further delves into stating the working hypothesis and also describes the independent or explanatory variables that affect the dependent variable (adoption decisions) of households regarding rooftop rainwater harvesting activities based on theoretical and empirical reviews and findings.

The Dependent Variable

For the purpose of this study objective, the decision of a given household to adopt or not adopt rooftop harvesting technology was treated as a dichotomous variable (a variable with only two possible outcomes) using a binary logistic regression model. A Household was only considered to be an adopter of rooftop rainwater harvesting technology if that particular household is formally harvesting rainwater using above or underground storage facilities. In view of this, households that were considered as adopters of rooftop rainwater harvesting technology were assigned a value of 1 and non- adopters were assigned a value of 0.

Explanatory Variables

Literature based on the findings of several studies suggests that technological, attitudinal, socio-demographic, economic, climatic and other factors directly influence households' decisions to adopt rainwater harvesting. The explanatory variables considered in the analysis and their expected effects on the adoption of rainwater harvesting technology by households are discussed below using theoretical and empirical findings.

Socio-demographic factors that affect households' decision to adopt rainwater harvesting

Age of household heads

Dasgupta (1989) was of the view that the age of household heads is one of the demographic factors that influence household decisions to adopt rainwater harvesting practices as a means of supplementing existing water sources. According to Dasgupta, older household heads are reluctant for new technologies and are more conscious to take risk of adopting a particular technology in case it fails to meet their expected outcomes. Household heads at old age tend to demand less water than young household heads who demand much water (Ahmed et al, 2013). DTU (2002) declares emphatically that households heads who are very old have less or no interest in participating in rainwater harvesting based on findings from a study conducted in Ethiopia and Srilanka. Bekelle and Holden (1998) supported this by saying that there is a negative association between adoption of rainwater harvesting and age in the Ethiopian highlands and therefore, adopters are relatively younger and middle-aged. Based on the above findings, age of household heads is a continuous variable and has being hypothesized that there would be an inverse relationship between household decisions to adopt rainwater harvesting technology and age.

Marital status of households heads

It is generally assumed that household heads who are married demand more water for various activities than those who are single and therefore the adoption decision is expected to have a positive link with married household heads (Gebregziabher, Rebelo, Notenbaert, Ergano, & Abebe, 2013). Marital status is a dummy variable with a value of 1 assigned to married household heads and a value of zero for single household heads.

Household size

Literature suggests that household decision to adopt rainwater harvesting technology is influenced by the household size or the number of people in the household (Kariuki, 2011). As a result of this, the larger the size of a given household, the more water demanded to cater for the needs of household members.

Social factors

Educational level of household heads

This variable is a dummy or discrete parameter with a value of 1 assigned to formal education (Basic, Secondary and Tertiary) and 0 for informal (any other form of education). Education level of household heads is assumed to affect their participatory decisions positively (Kariuki, 2011). The findings of Kassie, Jaleta, Shiferaw, Mmbando and Mekuria (2012) suggest that adopters of rainwater harvesting practices have higher educational level (formal) than non-adopters because they have being educated and exposed to most of these practices and hence their willingness to accept and adopt. It is anticipated that households' heads with formal education adopt rainwater harvesting technology because of their awareness of the multiple benefits derived from using it (Alemayohu 2013). Therefore, in most adoption studies, household heads with higher levels of education attainment are more likely to adopt or to practice rainwater harvesting techniques compared to less educated household heads (Chianu & Tsujii, 2005).

Households' perceptions on the quality of existing water sources

It is assumed that households' perceptions on the quality of existing water sources influence their rainwater harvesting adoption behaviours (Peterson, 1999). The perception on water quality is a dummy variable with a value of 1 for households who perceive that rainwater is of a higher quality and 0 for those who perceive rainwater to be of low quality. If households perceive the existing water sources in the municipality to be of high quality, then, the decision to harvest rainwater will be low (Nyamieri, 2013). It is anticipated that there is an inverse association between quality of existing water sources and adoption of rainwater harvesting.

Households' perception on the reliability of the existing water sources

It is hypothesized on theoretical basis that, if households perceive that there is adequate and reliable supply of water in the Municipality, their decisions regarding the adoption of rainwater harvesting will be low Alemayohu (2013). On the other hand, if water supply is inadequate and unreliable, rainwater harvesting activities will receive much attention. In view of this, an inverse link is expected between reliability of existing water sources and adoption activities of rainwater harvesting. This variable is a dummy variable and 0 was specified for households who perceived that there is reliable supply of existing water and 1 for households who do not.

Economic factors

Monthly income of households

Literature suggests that there is a direct association between household's decision to participate in rain water harvesting technology and income (Domenech, March, & Sauria, 2013). The income level of households determines their ability to provide household facilities such as roofing materials and tanks (Zingiro, Okello, & Guthiga, 2014). This also backs the theory of demand which states that income and quantity demanded for a normal good are positively related. Based on this, income level of households was measured as a continuous variable and a positive relationship was expected to emanate from the outcome of the econometric model.

Housing or building ownership

Investment decisions regarding the adoption of rainwater harvesting activities partly depends on house ownership (Murgor, Owino, Cheserek, & Saina, 2013). Houses that are owned by households are more likely to adopt rainwater harvesting technology than households who stay in apartments that have been rented. This is because occupants may move at any point in time or may be asked to vacate houses by landlords. This therefore deters households from adopting rainwater harvesting technology. Housing ownership is therefore anticipated to have positive influence on the readiness of households to adopt rainwater harvesting technology.

Attitudinal factors

Households Attitude towards the importance of rainwater

Bekelle and Holden (1998) suggest that there is a direct or positive link between the attitudes of people and their adoption behaviour of rainwater harvesting technology (Baiyegunhi, 2015). Apart from income and technological factors, the attitude towards rainwater usage significantly affects its adoption (Bhutani & Sehgal, 2014). It is anticipated that a positive relationship exists between adoption of rainwater technology and the attitudes of households in the municipality (Bekele & Holden, 1998).

Technological factors

Affordability of technology

The affordability of rainwater harvesting technology (the cost of tank and installation of system) influences households' ability to accept and adopt rainwater harvesting technology (WaterAid, 2013). Literature indicates that there is a negative association between households with low income level and investment cost of acquiring tank for rainwater harvesting. As households increase their tank size to harvest more water, the costs of tanks increase with tank size. This is backed by the demand theory that price increases as demand for a given commodity reduces. Although there are other exceptional factors to this law, it was hypothesized that an inverse relationship is expected on affordability technology and cost of acquiring the technology.

Other factors that influence households' adoption decision to harvest rainwater and were used in the logit model include encouragement of households, rainwater treatment, level of awareness, experience on water shortages, the use of simple technology, availability of skilled labour and government support to households in the form of technical experts and storage facilities.

Analysis of Spatial Data

This part of the study presents the methods used in analysing the spatial data. It begins with a brief explanation on the selection of roofs catchments and digitisation of rooftop surfaces to update existing data using Google Earth software. It also delves into the methods of data analysis (spatial data) and estimates storage capacity required to store rainwater using the average rooftop in the municipality. It ends with testing of harvested rainwater quality using Ghana Standard Authority water quality parameters.

Target Roofs and Sampling Techniques for Rainwater Harvesting

In order to estimate the amount of rainwater that can be captured from rooftops, all roofs of buildings were considered using census data and included in the study.

Determination of Runoff Coefficient

Runoff coefficient simply refers to the proportion of rainwater that is carried by the catchment surface, which in this case is rooftop, into a storage device (cistern). In other words, it is the ratio of the volume of water that runs off a surface compared to the total volume of rain falling on that particular catchment area (Gould & Nissen-Peterson, 1999; Fewkes, 2006).

This coefficient is a dimensionless number that ranges between 0 and 1.0 (Marsh, 2010). A runoff coefficient of 0 indicates that a roof surface carried no rainwater and a value of 1 indicates 100 percent runoff without any loss of rainwater. Based on the findings of Lancaster (2006), runoff coefficient for roofs ranges from 80 percent to 95 percent. There are inefficiencies associated with runoff coefficient and these are mainly attributed to evaporation and minor infiltration into the catchment surface itself (Lancaster, 2006). Different roof types generally have different efficiency rates. For example, pitched metal roofs are generally the most efficient with 95 percent efficiency (0.95 runoff coefficient); 90 percent for concrete or asphalt and 80 percent to 85 percent coefficient for built-up tile and gravel roofs (Lancaster, 2006).

In Adentan Municipality, the most dominant roof types and their corresponding percentages based on the 2010 Population and Housing Census Regional Analytical Report were tiles (9.7 percent), metal sheet (63.6 percent,) concrete/cement (3.8 percent), and asbestos/slates (20 percent) as shown in Table 1. Based on the findings of Lancaster, 90 percent (0.9) which represents an average value of runoff coefficient for the three dominating roofs types was used for the study.

Table 1: Type of Roofing materials found in the Adentan Municipality

Type of Material	Percentage
Metal Roofs	63.6
Concrete/Cement	3.8
Tiles	9.7
Asbestos/Slates	20.0

Source: Adapted from the 2010 Population and Housing Census Regional Analytical Report (GSS, 2013)

Hydrological Analysis

The method used in calculating the rainwater harvesting potential was derived based on the experimental evidence articulated in 1865 by Mr. H. Darcy, a French scientist. This was a law governing the rate of flow or discharge through soils. According to Darcy, the discharge that occurs in soils (Q) is directly proportional to head loss (H) and the cross-section (A) of soil, and inversely proportional to the length of the soil sample (L). Mathematically, this is expressed in the form Q = $\alpha \frac{H}{L}$ .A...... (1); where, Q = Runoff, H/L represents the head loss or hydraulic gradient (I) and α is the co-efficient of permeability K. Replacing $\frac{H}{L}$ and α with I and K respectively into equation..... (1), this implies that Q = K. I. A.

Similarly, based on the above principle, the formula for estimating rainwater harvesting potential of the roof catchment area was derived. The formula for estimating rainwater harvesting potential (volume of water received or runoff produced or harvesting capacity) is given as: $Hw = R * A * Cr$. Where, Hw is harvested rainwater potential or volume of water received

(m^3). R = amount of rainfall (m), A = area of Catchment (m^2) and Cr = runoff coefficient. Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface (Lancaster, 2006). Runoff coefficient accounts for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which all contribute to reducing the amount of runoff (Erwin, 2007).

Data Processing

Data captured in Google Earth with its format in KML was converted into feature class in ESRI geodatabase using ArCGIS software version 10.1. This was done through the use of the data interoperability tool of ArCGIS software. Afterwards, an import function was performed using Keyhole Markup Language as the input data with the desired output being the geodatabase. The coordinate system of the converted data was re-projected into a projected coordinate system (Ghana Meter Grid) which provided a best fit for the area of study and also helped in a better analysis of the data. Columns were created in the attribute table of the captured vector layers (roof-top) and with the aid of the raster field calculator in ArCGIS software, the total area of rooftop, annual potential harvested rainwater and monthly potential rainwater. Annual potential rainwater was calculated using the average rainfall of the 30 year period whist monthly potential rainwater was calculated using average monthly rainfall for the same period. Microsoft Office Excel 2013 basic functions like auto sum and average was used to analyse the mean monthly and mean annual rainfall data.

Generated potential rainwater harvest was analysed for the entire period which gives the average potential rainwater that can be harvested yearly. Potential rainwater that can be harvested monthly was also calculated to identify the particular months of the year that yield the highest rainwater. The lowest and the highest potential rainwater harvested was estimated based on the minimum, maximum and average rooftop which served as a guide in determining the capacity of storage facilities required by households to store rainwater in the Adentan municipality.

The capacity of storage size was estimated based on potential rainwater supplied by multiplying the average rooftop in the municipality by the average rainfall of the 30 year period and a runoff coefficient of 0.9. Expressing this mathematically, $Sc = Ar \times R \times Cr \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$ where; Sc = Capacity of storage size, Ar =Area of Average rooftop in the municipality, R = Average annual rainfall and Cr = Runoff coefficient. Given that average rooftop area in the Municipality was 156.3m^3, average annual rainfall of 0.6841 m^3 and runoff coefficient of 0.9. Then, substituting the values into equation 1, Capacity of storage size $= 156.3\ \mathrm{m}^3 * 0.6841\mathrm{m}^3 * 0.9 = 96.2\ \mathrm{m}^3$ Converting $96.2\ \mathrm{m}^3$ to litres $= 96.2\ \mathrm{m}^3 * 1000 = 96200$ litres.

In the case of water quality, rainwater samples from two storage tanks meant to supplement both potable and non potable water were randomly collected on two different occasions in the municipality and tested in the laboratory. The first samples were taken in March and the second samples were taken in June, 2015. One was taken from the High income area whilst the other was taken from the low income area. The water quality parameters tested were colour, turbidity, pH and coliform after which the results were compared with the Ghana Standard Authority water quality standard.

Presentation of results

A map was generated to show the results of the digitised rooftop while tables and graphs were used to show the potential rainwater that can be harvested.

Ethical issues

Ethical issues have become an important part of the research process as the violation of rules pertaining to right and use of information increases. In order not to misuse any information or data used in the study, the issues of informed consent, confidentiality and anonymity of respondents were given consideration in the study. First, the purpose of the study was made known to respondents. On the issue of informed consent, permission was sought from respondents before engaging them in the study. Respondents who took part in the study did that willingly without being influenced in anyway.

A brief overview of the questionnaire was given to respondents to know the nature of information required and the need to participate in the study. The respondents were also assured that any information provided would be used solely for academic purposes and hence their responses would be treated confidentially and kept safe without making it available to other persons for any other reason. Respondents were also assured of their anonymity by excluding their names, addresses and any other personal information that may possibly reveal their identity from the questionnaires. The privacy of respondents was respected and therefore any information that was deemed as private and has the possibility of creating inconveniences to respondents was avoided in the study.

The fast pace of development of Geographic Information System and Remote Sensing has also raised several ethical issues as to the capture of geographic features for private and public use, functions and access to the data. This has led to high damages being imposed by Google in the misuse of its geographic data of certain facilities in the world. Based on this, ethical clearance was sought from the Department of Geography and Regional Planning for this study. In capturing the roofs of buildings especially for residential accommodation, no attempt was made to link individual buildings to occupants of buildings captured. Their addresses and street names and other attributes that are likely to link a specific building to its occupants were ignored, and only the spatial extent of building rooftops in the municipality and their sizes were considered.

Summary

This chapter described the methods used for the study. It started with a brief introduction of the study area, followed by the study design, target population and determined the sample size required for the study. Other areas covered were the sampling procedure, types of data used as well as the sources and instruments used in data collection. The chapter further provided information on the fieldwork (data collection), challenges encountered and how these were addressed. In addition, the data analysis procedures for both household and geographic data were also elaborated on. The chapter finally ended with the use of binary logistic model in determining rainwater harvesting adoption behaviour of households, selection of runoff coefficient for rooftops and ethical consideration that were observed in the study.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Introduction

This part of the study presents the findings based on the fieldwork. This section consists of two main parts. The first part briefly presents findings on general issues facing the municipality. It also describes the socio-demographic characteristics of the study population in the Adentan Municipality. The second part therefore presents the findings that emanated from the fieldwork and discussion is made based on the findings. The motive of the discussion is to ascertain whether the major findings are consistent with existing findings in order to establish some kind of relationship and if not, find out the reasons why certain results differ from what exist in the literature.

The study follows in this order, assess the extent of rainwater harvesting in the municipality, determine the storage capacity required to store rainwater by household in the municipality, investigate the quality rainwater in the municipality, estimate the amount of potential rainwater from rooftops and determine factors that influence the adoption of rainwater harvesting technologies in the study area.

The study sought to find out major developmental challenges facing the Municipality in order to determine whether it was worth conducting the study. In view of these, respondents were asked to indicate some developmental challenges facing their communities in the order of their seriousness. From Table 2, the survey results showed that poor power supply or "dumso" was the current major challenge and represents 34 percent of the 196 respondents, and this was followed by inadequate water supply 26 percent. Waste management constituted 21 percent, while bad roads and poor drainage system recorded the same value of 10.7 percent.

Table 2: Major developmental challenges facing the Adentan municipality

Developmental Challenges	Frequency	Percentage
Inadequate water Supply	51	26.0
Poor Waste Management	25	12.8
Poor Power supply	68	34.7
Bad Roads	21	10.7
Poor Drainage system	21	10.7
Unemployment	10	5.1
Total	196	100.0

Source: Fieldwork (2015)

Access to potable water was one of the developmental challenges that were raised by the respondents (26.0 percent). In view of this, household heads were asked to determine their level of perception on how they agreed or disagreed that their community has a problem with access to adequate potable water supply (Table 3). From Table 3, more than half of the respondents (87.2 percent) agreed while 12.8 percent disagreed that access to adequate potable water supply was a challenge in their communities. According to respondents who agreed, the construction of the George Walker Bush High way led to a massive destruction of most of the old pipelines in the municipality.

Table 3: Access to adequate potable water supply as a challenge in Adentan Municipality

Response	Frequency	Percentage
Agree	171	87.2
Undecided	0	0.0
Disagree	25	12.8
Total	196	100.0

Source: Fieldwork (2015)

Besides, a man said,

> *Government did not take into consideration repairing existing pipelines before the extension of water supply. Because of this, water has not reached the homes of many.* (male respondent, 57 years)

In an interview with a key informant from the Ghana Water Company Limited (the communication manager), he said,

> *There are still challenges that hinder the company from operating at optimum capacity. The challenges include the recent limited power supply required to pump the water into reservoirs, high cost of operations in terms of finances use to pay electricity bills, chemicals for purifying water, illegal connection, leakages and bust pipelines, which waste a lot of water. Non-revenue water accounts for 49.1 percent of the total water produced.*

It is very remarkable to know that out of the total water produced by Ghana Water Company limited, about 49.1 percent of it is lost in the revenue of the company. This is almost close to half of the total cost of water produced. In view of this, there was the need to probe further to know whether the people of Adentan had adequate water supply or not. He said,

> *I live in Adentan and there are some areas that [sic] water flows twenty-four seven, however there are a number of places with no pipelines* (Communication Manager, Ghana Water Company)

This finding is clearly in line with the ideas of household heads especially in the marginalised areas like Adentan village that they have never had access to water supply; hence, government has neglected them. However, the issue of water flowing twenty-four hours, seven days was not consistent with the findings obtained from the household data because in the areas that are served with water, the respondents said that water flows twice a week (Fridays and Saturdays).

There was the need to find out from the Communication manager how these challenges facing the company are being addressed especially to reduce non-revenue water to minimum level. He said,

> *We are embarking on a High Impact Performance Programme that aims at reducing non-revenue water to minimum levels so as to increase revenue collection. It also includes a policy that if people give tip off or information on people who do illegal connection to the company, 10 percent of whatever*

is recovered from the culprits would be given as incentives to people who give vital information to the company.

In the case of potable water supply identified as a challenge in the Municipality, there was the need to find out from the respondents how long this challenge has persisted in the area (Table 4).

Table 4: The number of years that water as a challenge has persisted in the Adentan Municipality

Number of Years	Frequency	Percentage
5 Years and Below	33	16.8
6-10 Years	49	25.0
11-15 Years	47	24.0
16-20 Years	49	25.0
21-25 Years	15	7.7
26 Years and Above	3	1.5
Total	196	100.0

Source: Fieldwork (2015)

About 16.8 percent said the water problem has persisted for 5 years, 21-25 years and at least 26 years recorded 7.7 percent and 1.5 percent of the respondents respectively. About 24 percent of the respondents said the water problem has being in existence for 11- 15 years while 6-10 years and 16-20 years recorded the same value of about 25 percent of the respondents. On average, the problem of inadequate water supply in the Adentan Municipality has persisted for at least 15 years.

The study also sought to find out the perception of the respondents, the extent to which individuals and the Municipal Assembly have addressed the water problem identified in the Adentan Municipality. From Table 5, about 55 percent of the respondents were of the view that both individuals and the Assembly are doing well in addressing the problem while 44.4 percent thought otherwise that both individuals and the Assembly are not doing much about addressing the water challenges in the municipality. However, since the percentage of the former outweighs the latter, it is a clear indication that both individuals and the Municipal Assembly are helping to address the problem of inadequate water supply.

Table 5: How individuals/Municipal Assembly are addressing the water problem

Status of Challenges	Frequency	Percentage
Being Addressed	108	55.1
Not Addressed	87	44.4
No Response	1	0.5
Total	196	100.0

Source: Fieldwork (2015)

The Socio-Demographic characteristics of Households

The study sought to find out the background characteristics of the household heads that were included in the study. Key variables analysed included sex, age, religion, educational level, number of people per household, monthly income and house ownership (Table 6).

Out of the total 196 household heads who took part in the study, males constituted 55.6 percent, whilst 44.4 percent were females. This result was close to the findings of the 2010 Population and Housing Census Regional Analytical Report where males constituted 50.3 percent and 49.7 percent in the Adentan Municipality (Ghana Statistical Service, 2010). Besides, in all districts within the Greater Accra region, the majority of household heads were males ranging from 55.3 percent in Dangbe East.

Table 6: Socio-demographic characteristics of respondents

Socio-Demographic characteristics	Frequency	Percentage
Sex		
Male	109	55.6
Female	87	44.4
Age		
19 and Below	6	3.1
20-29	47	24.0
30-39	55	28.1
40-49	49	25.0
50-59	26	13.3
60 and Above	13	6.6
Religion		
Christian	144	73.5
Islam	40	20.4
Traditional	12	6.1
Educational Level		
No Formal Education	7	3.6
Basic/Middle/JHS	65	33.2
Secondary/SHS/ Sixth form	75	38.3
Tertiary	49	25.0

N = 196

Source: Fieldwork (2015)

Table 6: Continued

Socio-Demographic characteristics	Frequency	Percentage
Number of people per household		
1-2	7	3.6
3-4	70	35.7
5-6	63	32.1
7-8	35	17.9
9-10	10	5.1
11 and Above	11	5.6
Monthly Income (GH₵		
200 and Below	31	15.8
200-400	62	31.6
400-600	34	17.3
600-800	26	13.3
800-1000	24	12.2
1000-1200	11	5.6
1200-1400	1	0.5
1400-1600	1	0.5
1600-1800	1	0.5
1800 and Above	3	1.5
No Response	2	1.0
Household Ownership		
Rented House	91	46.4
Private/Self owned	105	53.6

N = 196

Source: Author's Fieldwork (2015)

The study sought to look at the age distribution of households who were involved. The age group of 30-39 recorded the highest respondents of 28.1 percent, followed by 40-49 with 25 percent and 24 percent for respondents within the age group of 20-29 years. This result is also almost in line with the 2010 population and housing census Regional analytical report where most of household heads (55.1 percent) in Greater Accra were aged 25-44 years.

In the case of marital status of household heads used in the study, about 54.1 percent were married and 31.1 percent indicated that they were not married. This is vital because household heads who are married and have children with other dependants have a greater economic and social responsibility of providing their dependants with access to water supply.

With respect to the religion of household heads involved in the study, the survey results in Table 6 showed that the most dominating religion in the Municipality was Christianity represented by about 73.5 percent of the respondents while 20.4 percent were Muslims. This was as a result of the fact Christianity had early contact with the Southern part of the country whilst Islam also entered from the North before spreading to the interior.

In the case of educational level attained by household heads, generally, household heads in the Municipality have attained formal education with 38.3 percent representing Secondary/Senior High School/Sixth form, 33.2 percent was for Basic/Middle/Junior High School, and 25 percent representing respondents with Tertiary level of education.

The average number of people per household in the municipality was 3.2. Households with 3 to 4 persons constituted 35 percent, whilst about 32.1

percent and 17.9 percent represented households with 5-6 and 7-8 persons respectively. The mean value (persons per household) is close to the 2010 Population and housing census report of an average household size of 3.7 in Adentan municipality.

Income was one important issue considered during the fieldwork work and in this context, it was mainly treated as socio-demographic and economic variable that helped in the determination of factors that influenced household's decision to adopt rainwater-harvesting technology. Finding the monthly income of household heads was a very sensitive issue because most of the respondents were not willing to give their exact monthly incomes especially in the high-income areas (Adentan Estate) as compared to those in low-income areas (Adentan Village). From Table 6, most of the household heads earned monthly income that ranged between 200 and 400 Ghana Cedis.

Household ownership status was another variable considered in the study. This was also considered as both an economic and a socio-demographic variable. However, it was primarily included in the regression model to ascertain the influence it has on adoption or non-adoption of rainwater harvesting. The study revealed that 46.4 percent of the 196 respondents in the Adentan Municipality lived in rented houses while 53.6 percent of the respondents lived in private or self-owned houses.

The Extent of Rainwater Harvesting

This section talks about the extent of rainwater harvesting in the Adentan Municipality. Specifically, issues that have been addressed here include water demand, storage size, rainwater quality and how often households harvest rainwater. Although some people of Adentan Municipality have harvested rainwater for a long time, not until December 2014, access to pipe borne water was a rare commodity in the municipality. In view of this, the study sought to determine whether the respondents were aware of rainwater harvesting (Table 7).

Table 7: Awareness of rainwater harvesting in Adentan Municipality

Level of Awareness	Frequency	Percentage
Aware	180	91.8
Undecided	0	0.0
Not Aware	16	8.2
Total	196	100.0

Source: Author's Fieldwork (2015)

The results in Table 7 clearly confirm that most of the respondents were aware of rainwater harvesting. About 92 percent of the respondents were aware of rainwater harvesting while 8.2 percent of the respondents said they were not aware of rainwater harvesting as they rely on other sources of water supply. A key informant (Planning Officer) in the municipal Assembly indicated that

> *The Assembly encourages individuals to harvest rainwater as a means of supplementing the acute water shortages. However, the Assembly has not being able to support individuals due to financial difficulties.*

In the case of respondents who were aware of rainwater harvesting, there was the need to ascertain from them how often they harvested rainwater. The results in Table 8 reveal that about 76.0 percent of the respondents often harvest rainwater, followed by 18.9 percent of the respondents who said they seldom harvest rainwater. About 5.1 percent said they had never harvested rainwater. In spite of the number of respondents who have never harvested rainwater, households in Adentan municipality often harvest rainwater.

Table 8: The regularity of rainwater harvesting

Response	Frequency	Percentage
Often	130	76.0
Seldom	37	18.9
Never	10	5.1
Total	196	100.0

Source: Fieldwork (2015)

Rainwater has multiple uses in Adentan Municipality such as the main source of potable water or a supplementary source of both potable and non-potable water supply. From the study when respondents were asked to assess how beneficial rainwater was, 93.9 percent of the respondents were of the view that rainwater was beneficial, while 6.1 percent said that it was not beneficial (Table 9).

Table 9: Benefits of rainwater harvesting as perceived by respondents

Response	Frequency	Percentage
Beneficial	184	93.9
Undecided	0	0.0
Not Beneficial	12	6.1
Total	196	100.0

Source: Fieldwork (2015)

According to some of the respondents, rainwater harvesting is very beneficial not only in terms of potable and non potable uses but also because it contributes to localised flood reduction especially for those who live in low lying areas as they are liable to flood during the rainy season. Rainwater as a supplement to other sources of water the potential of saving especially conventional water supply and this is congruent with the studies of (Lade, Coker and Scridhar, 2012; Lekwot, Samuel Ifeanyi and Okisaemeka, 2012; Mourad and Berndtsson, 2011; Shittu, Okareh and Coker, 2012) that rainwater has the potential of saving conventional water supply.

Though government is making progressive efforts to making potable water supply accessible to all people in the municipality, residents were of the opinion that rainwater should be encouraged in the municipality. The fieldwork result indicated that 92.4 percent of the respondents agreed that rainwater harvesting should be encouraged in the Adentan municipality while about 7.6 percent disagreed because for them, they have access to the conventional water supply and thought they were better off than worse off (Table 10).

Table 10: Encouragement of rainwater harvesting in the Adentan Municipality

Response	Frequency	Percentage
Agree	181	92.4
Undecided	0	0.0
Disagree	15	7.6
Total	196	100.0

Source: Fieldwork (2015)

The Planning Officer from the Municipal Assembly added that

> *We encourage rainwater harvesting although we have not being able to assist households in terms of harvesting facilities.*

According to information obtained from the Ministry of Water Resources Works and Housing (2011), National RWH Strategy Final Report, there is no single policy document on rainwater harvesting but everything is integrated in the Water Policy document, which also puts much emphasis on rainwater harvesting as an alternative/supplement to other sources of water supply in contemporary times.

The people of Adentan Municipality rely on several sources of water supply which could be potable and non-potable (Plate 1). However, when respondents were asked to indicate the main sources of water supply in order of importance, water from wells dominated in the Municipality given that about 28.6 percent of the respondents used pipe borne water (Table 11).

Table 11: The main sources of domestic water supply in Adentan Municipality

Main Sources of Water	Frequency	Percentage
Wells	48	24.5
Boreholes	35	17.9
Pipe borne	56	28.6
Sachets/Water Vendors	20	10.2
Rainwater	9	4.6
All of the above	28	14.3
Total	196	100.0

Source: Fieldwork (2015)

Besides, about 24.5 percent of the respondents used water from wells and boreholes accounted for 17.9 percent of the total respondents. The Adentan Estate in the Municipality recorded the highest number of people in terms of pipe borne water supply it is a government project that was connected to pipe water and partly because most of the high-income groups lived in this area, hence have being able to extend the pipe borne water into their homes. On the contrary, an interview with most of the respondents indicated that they have a severe problem with water. For instance a man who lived at Adentan Village, said that

> *We have being neglected as not being part of the municipality. Our income levels are very low and besides, the main pipelines are far from our reach. So we can't afford to extend water into our homes* (male respondent, 52 years).

When a key informant from the water company (the Public Relations Officer) was asked to give some of the possible reasons why the company has not being able to operate at full capacity to meet the demand of the growing population, the response was that indeed the company faces numerous challenges. He said,

> *Among the key issues confronting the company include the irregular or limited power supply needed to pump water into reservoirs, financial challenges because most of our customers especially tertiary institutions that are publicly*


0548 637 798

percent of the respondents consumed 6-10 gallons per day while 14.3 percent used about 16-20 gallons of water daily.

Table 12: Households daily domestic water use

Daily Domestic water use (Gallons, x litres)	Frequency	Percentage
1-5	19	9.7
6-10	58	29.6
11 -15	68	34.7
16-20	28	14.3
21-25	10	5.1
26-30	6	3.1
31-35	2	1.0
36 and above	5	2.6
Total	196	100.0

Source: Fieldwork (2015)

Household heads were asked to indicate in order of importance the main uses of harvested rainwater. The following were the responses that emerged from the survey (Table 13).

Table 13: The uses of harvested rainwater by households

Rainwater usage	Frequency	Percentage
Potable uses alone	41	20.9
Non-potable use alone	50	25.5
Both Potable and Non-potable use	95	48.5
Not Applicable	10	5.1
Total	196	100.0

Source: Fieldwork (2015)

About 48.5 percent of household heads used rainwater for both Potable and non-potable purposes while 20.9 percent and 25.5 percent represented respondents who harvested rainwater for potable and none potable uses only respectively. Respondents who did not use rainwater at all (not applicable) because they could afford water supplied by tanker operators constituted 5.1 percent. The findings conform to the results obtained by (Shittu, Okareh & Coker, 2012; Lekwot, Samuel, Ifeanyi & Okisaemeka 2012) that harvested rainwater is used for augmenting both potable and non potable water sources.

Households in the Adentan municipality buy water from several sources with the least cost of about 20 pesewas per gallon of water which most often than not is Well water. Ghana water Company is yet to install water meters in the homes of those who have access to pipe borne water. Averagely, households' daily expenditure on water is about GH ₵ 4.00 (Table 14).

Table 14: Households daily expenditure on water

Daily Expenditure on water (Ghana Cedis)	Frequency	Percentage
0.10 -1.00	4	2.0
1.10 -2.00	34	17.3
2.10 -3.00	43	21.9
3.10 -4.00	35	17.9
4.10 -5.00	31	15.8
5.10 -6.00	28	14.3
6.10 -7.00	17	8.7
7.10 and Above	4	2.0
Total	196	100.0

Source: Fieldwork (2015)

This means that a household spends about GH ₵ 28.00 on water weekly. This is close to the figure given by a key informant from the Ghana Water company Limited which indicated that a household of about 4 persons spend about GH ₵ 30.00 on water per week (Table 14).

Household heads that took part in the study thought that the amount of money being spent on water was economical to them since they have no other choice than to buy it from the various sources (Table 15). From Table 15, the majority of the respondents (51.5 percent) said the expenditure on water was economical, as against (48.4 percent) who said the expenditure was rather expensive. Although the expenditure on water was economical as indicated by half of the respondents, comparing the percentage to those who believed that it was expensive gives a smaller difference.

Table 15: Households opinion on the expenditure of daily water supply in Adentan Municipality

Response	Frequency	Percentage
Economical	101	51.5
Undecided	0	0.0
Expensive	95	48.4
Total	196	100.0

Source: Fieldwork (2015)

Rainwater harvesting requires a storage device as a principal component for the system to be complete and one's ability to harvest rainwater largely depends on storage tank. Therefore, Table 16 provides a list of storage facilities found in the study area. Buckets/barrels/pans dominated (47.5 percent) in the area especially in Adentan village, followed by

Types of Storage Facilities	Frequency	Percentage
Tanks/reservoirs	80	40.8
Buckets/barrels/pans	93	47.5
Local pots	13	6.6
Not Applicable	10	5.1
Total	196	100.0


FEMALE
MALE

litres were also represented by about 9.7 percent, 3.6 percent, 6.6 percent and 7.7 percent in that order. Storage tanks for rainwater harvesting in the municipality were of different sizes and this is in line with the findings of Canada Mortgage and Housing Corporation (2013) and Fewkes (2006) that domestic rainwater storage tanks come of different shapes and sizes and are made up of different materials.

Table17: The capacity of storage facilities

Storage tank sizes (litres)	Frequency	Percentage
500 and Below	77	39.3
501-1000	43	21.9
1001-1500	22	11.2
1501-2000	19	9.7
2001-2500	7	3.6
2501-3000	13	6.6
3001 and Above	15	7.7
Total	196	100.0

Source: Fieldwork (2015)

Rainwater Quality

One of the specific objectives was to solicit the opinions of household heads as to whether rainwater has to be treated before used for potable purposes or not. However, the survey result in Table 18 indicates that under one must treat rainwater when the intension is for drinking. About 70.9 percent of the respondents agreed that rainwater should be treated in this case while 29.1 percent of the household heads thought otherwise (Table 18). This clearly indicates that rainwater is generally of good quality but at instances when it intention is mainly for drinking purposes it must still require some level of treatment. The result is consistent with Lade (2013) that rainwater meant for potable purpose requires treatment before use.

Table 18: Perception of household heads on rainwater treatment

Response	Frequency	Percentage
Agree	139	70.9
Undecided	0	0.0
Disagree	57	29.1
Total	196	100.0

Source: Fieldwork (2015)

Although the findings from the household data indicate that rainwater was of good quality, there was the presence of coliform contamination in the test results of water samples collected from different locations in the municipality. Table 19 shows the water quality parameter tested; the Ghana Standard Authority quality standard (maximum), and the test results (average) of the rainwater samples collected. For colour (Hazen) and turbidity, the test result showed an average value of 7.0 and 3.0 respectively. This is more desirable because these results do not exceed the Ghana Standard Authority quality standard. In the case of pH (Hydrogen Potential), the result was 6.9, which is almost close to neutral. Coliform and fecal coliform must not be detected in 100 ml sample of rainwater according Ghana Standard Authority, however the test result exceeded 25.0.

The higher coliform found in the water samples may be influenced by the presence of poor sanitation practices such as the presence of faeces and refuse dumps found in most urban centres and are not disposed off on time. In addition, birds like crows, vultures and other reptiles like lizards that defecate on roofs, conveyance (gutter) and in storage facilities may also be a major source of contaminants that led to the presence of coliform in the rainwater samples.

Table 19: Rainwater sample test results in Adentan Municipality compared with that of Ghana Standard Authority parameters

Water Quality Parameter	GSA Water Quality Standard (max)	Results of sample Tested (Average)
Colour	15.0	7.0
Turbidity	5.0	3.0
PH	6.5-8.3	6.9
Coliform per 100 ml	Must not be present in 100 ml sample	>25.0
Fecal Coliform per 100 ml	Must not be present in 100 ml sample	>25.0

Source: Fieldwork (2015)

Various methods were used in purifying water, but in the case of rainwater 51.5 percent of the respondents used filtering materials to filter harvested water (Figure 6). Also, about 30.6 percent preferred boiling rainwater before use, whilst 12.8 percent used chemicals especially alum in the treatment process. About 5.1 percent of the respondents constituted the number of household heads who do not harvest rainwater in the municipality because they rely mainly on other sources of water supply. Household heads preferred filtering, boiling and chemicals as suggested in the studies of (Clasen & Edmondson, 2006; Lantagne, Quick & Mintz, 2007).

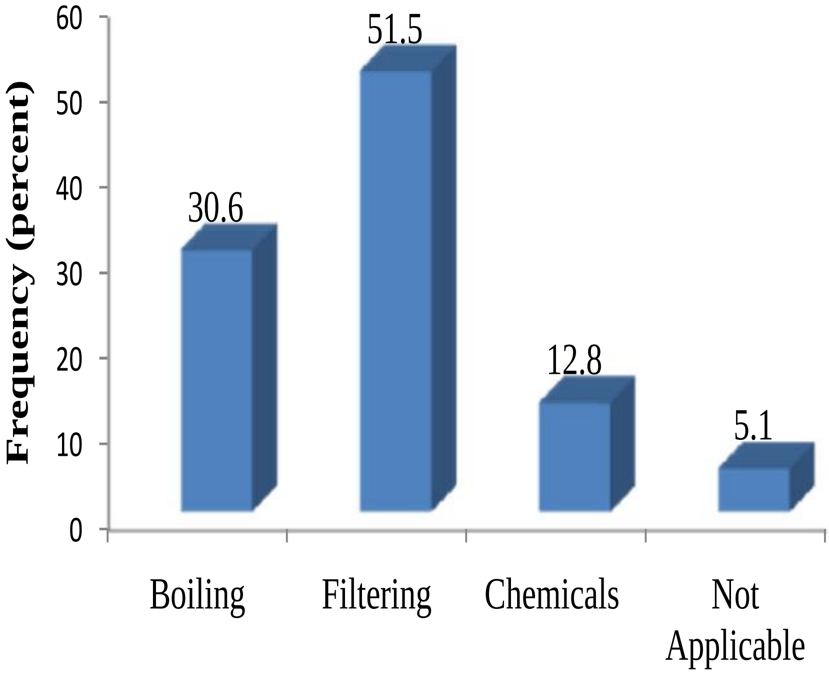


Figure 6: Methods of treating rainwater by households in order of importance

Source: Fieldwork (March, 2015)

A Laboratory Technician from the Ghana Water Company confirms that

> *In terms of urban water supply, there are many parameters are used in checking the quality of water supplied. However, for the purpose of rainwater its intended use determines the kind of treatment that is used* (male respondent, 37years).

A laboratory analysis of water samples taken from the study area proved that the presence of coliform is an indication that it is not safe for drinking although the results were very close to the WHO standards and the Ghana

Standard Authority. Despite this result obtained from the laboratory test, the Regional Chief Engineer of the Community Water and Sanitation Agency also said,

> *The quality of water can change during certain periods and hence should be tested at least twice a year.*

When household heads were asked to rank the quality of harvested rainwater, majority of the respondents ranked the quality of rainwater as good and the remainder ranked it as bad (Table 20).

Table 20: Assessment of rainwater quality

Rainwater Quality	Frequency	Percentage
Good	168	85.7
Undecided	0	0.0
Bad	28	14.3
Total	196	100.0

Source: Fieldwork (March, 2015)

According to some of the respondents, any time it rains all the dirt on roofs is washed away in about the first 10 minutes and any water harvested after 10 minutes time is of good quality and is suitable for drinking. In view of this, rainwater can be of high quality if only the appropriate catchment, storage unit, and treatment are used. The finding is also consistent with the findings of (Despins et al., 2009; Efe, 2006; Olaoye & Olaniyan, 2012).

Potential Rainwater Harvested using Rooftops

This section presents the results on potential rainwater harvested using rooftops in the study area. Potential rainwater was estimated using rooftops and annual average rainfall calculated based on a thirty-year period (1982-2012). The first part presents the analysis of the rainfall data and the second part presents the results of potential rainwater using the mean annual rainfall for the entire period and mean monthly rainfall for some selected months of the time series data with the total roof area of the study area using Arc GIS Version 10.1. The section finally ends with a map of the Adentan Municipality showing rooftop generated using Arc GIS Version 10.1

Rainfall variability in Adentan Municipality

Rainfall distribution in the Adentan Municipality varies from one year to another. Based on the 30-year rainfall data used in the analysis, the year 1997 recorded the highest rainfall whilst the year 1983 recorded the lowest rainfall.

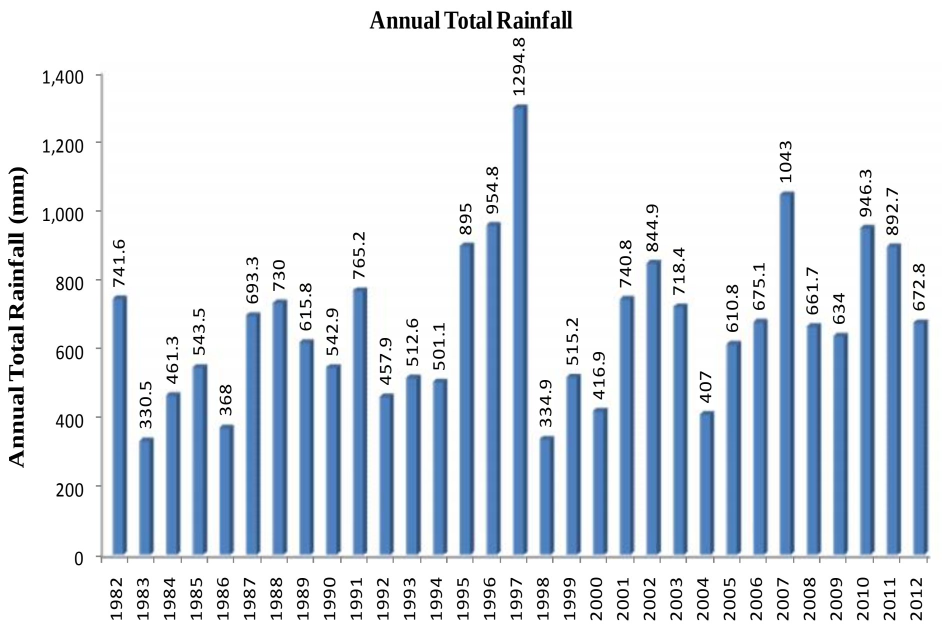


Figure 7: Bar chart showing rainfall variability in Adentan Municipality (1982-2012)

Source: Fieldwork (March, 2015)

Average monthly rainfall was also another important element that was considered as it helped in knowing the specific months that rainwater harvesting was considered more feasible. Mean monthly rainfall ranged from 6.3 mm to 168.5 mm with the highest occurring in June and the lowest in January (Figure 8).

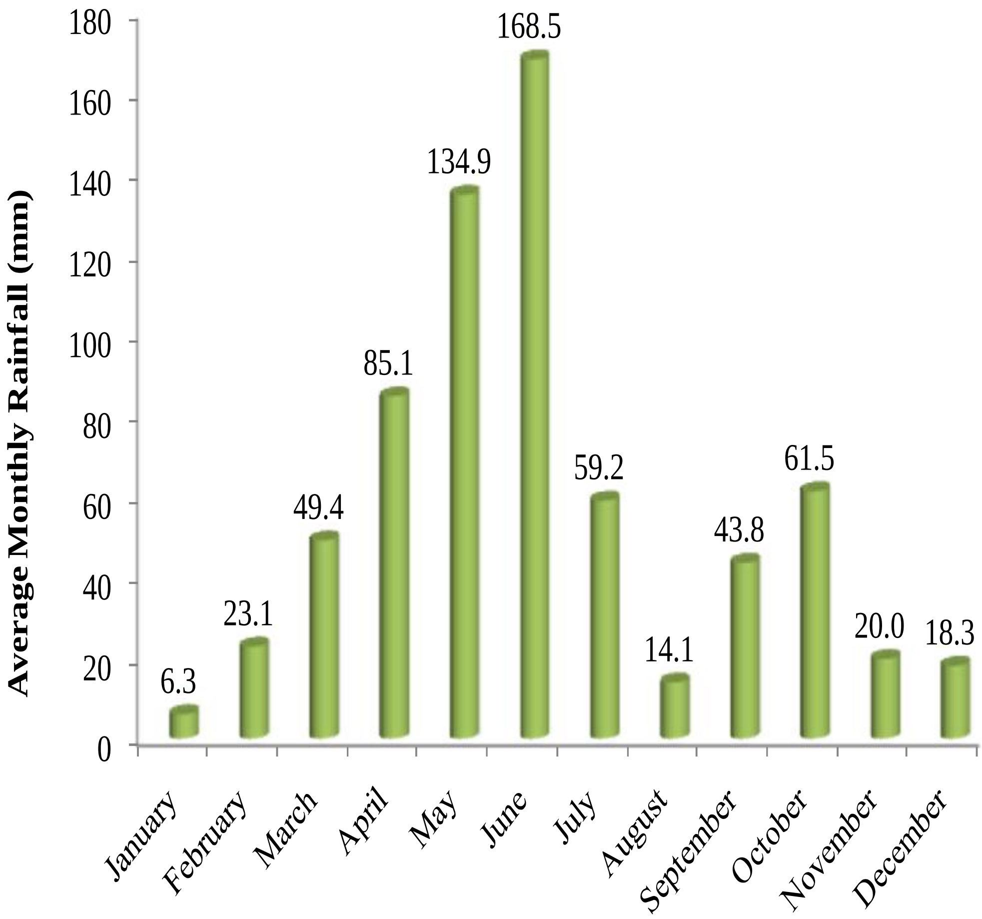


Figure 8: Average monthly rainfall in Adentan municipality (1982-2012)

Source: Fieldwork (March, 2015)

The total number of structures digitised within the study area was 344,991. Out of these total roofs captured in the form of vector layers (polygons), the minimum rooftop was estimated to be 1.63 m^2 while the maximum was 9148.5 $m^{2.}$ The sum of rooftop areas digitised in the Adentan municipality was 53,921,690.8 m^2 and the mean (Average) rooftop was 156.3 $m^{2.}$ The potential annual rainwater that can be harvested in the Municipality using rooftops was 33,199,045.8 m^3. This has a minimum value of 0.1m^3 and a maximum value of 5632.6 m^3. Therefore, the annual potential rainwater that can be harvested is 33199045.8 m^3 or 33199045800 litres.

The study again sought to find out the potential rainwater that can be harvested in each month of the year (Table 21).

Table 21: Monthly potential rainwater that can be harvested using rooftops

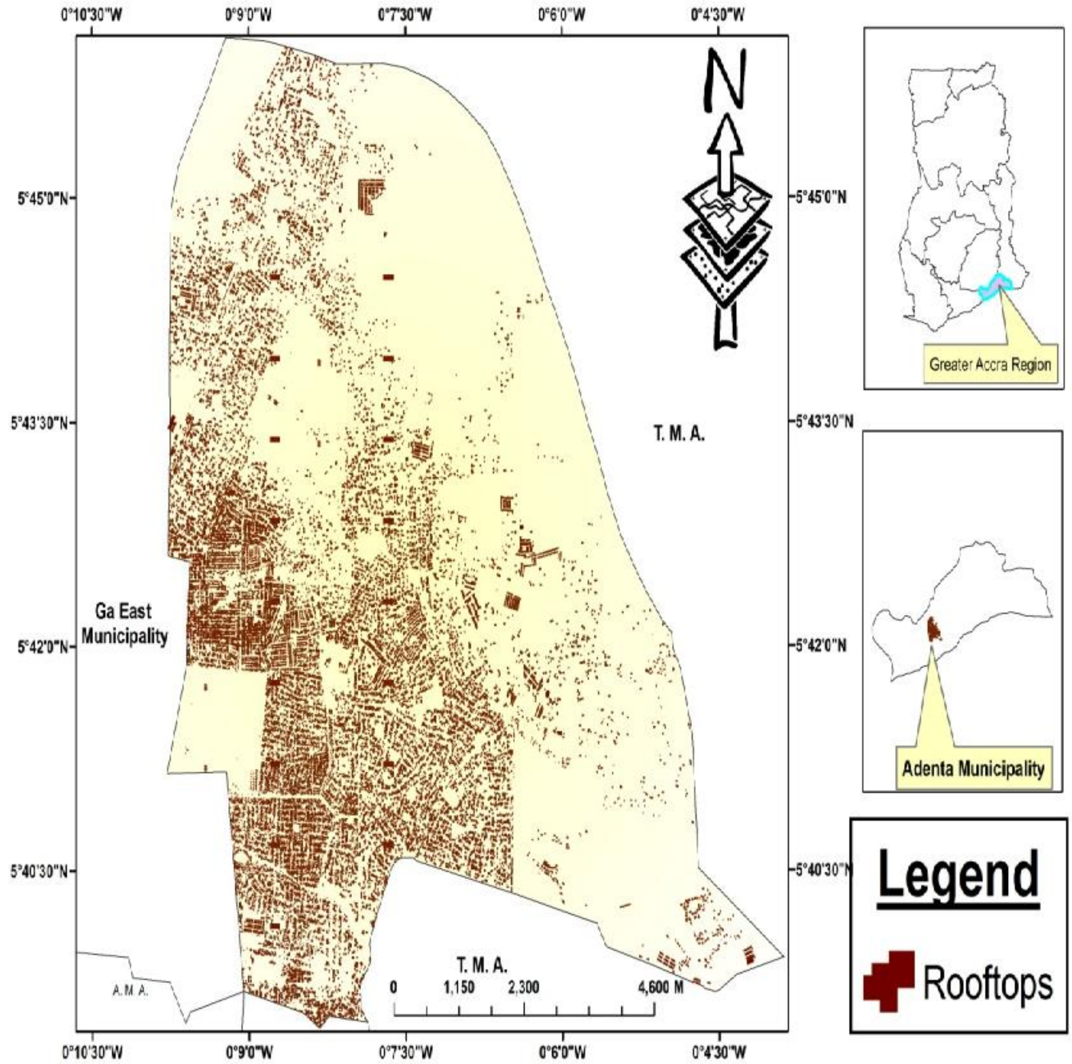
Months	Mean Monthly Rainfall (m^3)	Potential Monthly Rainwater (m^3)
January	0.0063	305,736.0
February	0.0231	1,121,032.0
March	0.0494	2,397,358.4
April	0.0851	4,129,862.3
May	0.1349	6,546,632.5
June	0.1685	8,177,224.4
July	0.0592	2,872,947.7
August	0.0141	684,266.3
September	0.0438	2,125,593.1
October	0.0615	2,984,565.6
November	0.0200	970,590.4
December	0.0183	888,090.2

Source: Fieldwork (2015)

This was necessary because having adequate knowledge on months that produce the highest amount of rainwater will serve as a guide to households to harvest more rainwater within such months. The potential monthly rainwater that can be harvested in Adentan municipality using mean monthly rainfall and a runoff coefficient of 90 percent is shown in Table 21.

From Table 21, Potential rainfall increased from January to May, attained its peak in June and declined steadily from July to August. This subsequently rose in September to October. January recorded the lowest potential rainwater with a value of 305736.0 m^3 while June recorded the highest potential rainwater of 8177224.4 m^3. January received the lowest rainfall because it is the month in which the harmattan is very intense while June recorded the highest because most of the rainfall begins in April and gets to its peak in June. In view of the above findings, rainwater should mostly be harvested from February to July and September to October because these are the periods where rainwater harvesting yields the maximum output. To round it off, the study revealed that rooftops in the Adentan Municipality have a greater potential of harvesting enough water to meet the needs of the growing population.

Harvested Rainwater requires storage facilities in order to store water for future use. Although the household data indicated that various storage facilities are used in the Municipality, yet most of these facilities were below 1000 litres and hence could not store adequate rainwater. The average rooftop in the Adentan Municipality was used to estimate storage capacity required to store potential rainwater based on water supplied. Therefore, sizing of rainwater storage tanks requires at least a total volume of 96.2 m^3 or 96200 litres to store potential harvested rainwater within a given year. This is at least 9 Rambo 1000 tanks, without regard to demand. The volume required could be



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Greater Accra Region
Adenta Municipality
Legend
Rooftops

Factors that Influence Households Decisions to Adopt Rainwater Harvesting Technology

This part presents the analysis of the variables used in the binary logistic regression model to determine factors that may likely influence the adoption decisions of household heads to harvest rainwater in the Adentan Municipality.

The characteristic of the binary logistic model is shown in Table 22. Specifically, the characteristics are; the Exp (B) (the odds ratio), Wald value which tests the unique contribution of each predictor by holding other predictors constant and eliminating any overlap between predictors, Sign (P-value) which represents the extent to which each predictor or independent variable is important to the entire model, and S.E. which represents the standard rrror in the model. Each independent variable in the model is only considered as significant to the model if it satisfies two main conditions (Pallant, 2005). These are; first, the predictor variable must have a combined odd ratio value of more than 1 and second; the predictor variable must have a significant P-value of less than .05 (Kinnear & Gray, 2002). In this case when the Exp (B) or odd ratio value is less than 1, increasing value of the variable corresponds to decreasing odds of the event's occurrence and vice versa (Adam, Adongo, & Dayour, 2014)

Table 22: Parameter estimates of the binary logit model for factors that influence households' decisions to adopt rainwater harvesting technology in Adentan Municipality

Variables in the equation	B	S.E.	Wald	Sign.	Exp(B)
Age	-2.188	.784	7.776	.005***	.112
Sex	2.706	.652	17.224	.000***	14.971
Marital Status	2.052	.645	10.106	.001***	7.782
Educational Level	-.171	1.762	.009	.923	.843
Income Level	1.383	.701	3.894	.048**	3.985
Household Size	-.363	.668	.295	.587	.696
Level of Awareness	21.198	8393.969	.000	.998	1607733270.216
Benefits of Rainwater	1.215	2.462	.243	.622	3.369
Encouragement of households	-1.765	1.989	.788	.375	.171
Cost of Storage Tank	.812	2.163	.141	.707	2.252
Rainwater Treatement	1.230	.760	2.615	.106*	3.421

Table 22: Table 22: Continued

Variables in the equation	B	S.E.	Wald	Sign.	Exp(B)
Perception on Rainwater Quality	2.523	1.781	2.007	.157	12.464
Household Ownership	2.638	.658	16.085	.000***	13.982
Experience on water shortage	-.734	1.791	.168	.682	.480
Access to Materials	.222	1.325	.028	.867	1.248
Simple Technology	-1.988	1.096	3.289	.070*	.137
Skilled Labour	.292	.912	.103	.748	1.340
Government Support	-3.308	2.003	2.725	.099*	.037
Size of Storage Facility	-.738	.753	.960	.327	.478
Constant	-21.820	8393.970	.000	.998	.000

Source: Fieldwork (2015)

Note: Number of observation = 196; $p \leq .05$; Nagelkerke R Square = .901; Hosmer and Lemeshow Test: Chi Square(X^2) = 13.267, df = 8, Sign (p-value) = .103, -2log likelihood = 97.253[a]; Omnibus Test of model Coefficients: Chi Square(X^2) = 171.688, df = 19, p-value = .000, overall accuracy percentage (percentage predicted correctly) of the model is .912; Also, *, ** and *** denote 10 percent, 5 percent and 1 percent significant level(s) respectively.

The age of household heads, given an odd ratio of .112 and a p-value of .005 has a significantly negative relationship with the adoption of rainwater harvesting. This means that adopters of rainwater harvesting are relatively young and middle aged people. An increase in the age of a household head by.112 yearly decreases the probability to adopt the technology by about 1. This result is consistent with the findings of Bekelle and Holden (1998) and the theory of human capital, that suggests that young household heads have a greater chance of absorbing and applying new knowledge than old household heads (DTU, 2002).

The binary logit model shows a significant relationship between sex (gender) and the rate of adoption with a positive effect as hypothesized. It is significant at 5 percent level and an odd ratio of 14.971 means that a household headed by a female is likely to reduce the rate of adoption by 1. Male-headed households are more likely to adopt rainwater harvesting than female household heads because they can afford the cost of installation and because it is the responsibility of males to provide such facilities at their homestead. Besides, males are very busy and do not have time to search for water as compared to their female counterparts who walk over long distances in search of water. This finding is consistent with the results of (Deressa et al., 2009; Kariuki, 2011; Shikur & Beshah, 2013) that adopters of rainwater harvesting tend to be males than females.

Marital status of household heads has a positive effect on adoption of rainwater harvesting and this is significant at 5 percent given an odd ratio of 7.782, which is a clear indication that household heads that are married and have children would need water regularly because of their responsibility in taking care of children. This result is consistent with the findings of Gebregziabher, Rebelo, Notenbaert, Ergano and Abebe (2013) household heads who are married adopt rainwater harvesting because they need adequate water to take care of their family.

Education level proved to have a negative effect on the adoption of rainwater in the municipality. An odd ratio of .843 with a p-value of .923 implies that one more year level of education of household heads reduces the probability of adoption by .843. The result is contrary to the findings of (Alemayohu, 2013; Kariuki, 2011; Kassie, Jaleta, Shiferaw, Mmbando & Mekuria 2012) who suggested that adopters of rainwater harvesting practices have higher educational level (formal) than non-adopters because they have being educated and exposed to most of these practices and hence their willingness to accept and adopt. The reason for this variation may be attributed to the fact that the educated people are concentrated in the Adentan Estates who have access to pipe borne water twice a week and also because they can afford water supplied by tanker operators than those who live in Adentan village with low level of education and no water supply.

Income level also has a statistically significant positive influence on the adoption of rainwater as expected in the study. Household heads with higher income levels are more likely to adopt rainwater-harvesting technology than those with lower income level. The odds ratio of 3.985 indicates that an increase in the income of a household head has the probability to increase the adoption of rainwater harvesting technology by 3.985. The result is also congruent to results obtained by (Domenech, March, & Sauria, 2013; Zingiro, Okello & Guthiga, 2014) that a household ability to install rainwater harvesting system depends on income level. Thus households with high income level can afford the cost of storage facilities than those with low income level.

Household Size was not significant and has a negative influence on household's rainwater adoption rate. As the size of a household increases, the probability of adoption of RWHT reduces by .696. This result is contrary to the findings of Kariuki (2011) and Shikur and Beshah (2013) that the rate of adoption increases with household size because they will demand more water. What may have accounted for this was that as household size increases, their expenditure also increases and hence their ability to invest in rainwater harvesting technology reduces.

Level of Awareness of rainwater harvesting was not statistically significant given a p-value of .998 but had a positive influence on adoption of RWHT. The odds ratio implies that as the awareness level of households' increases, probability of the decision to adopt also increases. The result is in line with that of Ahmed et al (2013) who found out that awareness of rainwater harvesting increases its rate of adoption.

The benefits of rainwater or the importance attached to rainwater by households although was not significant at 5 percent, had a positive effect on adoption of RWHT. The odds ratio of 3.369 is a clear indication that the more households perceive rainwater as beneficial the rate of adoption increases by 3.369. The result is in line with the findings of Bhutani and Sehgal (2014) and Alemayohu (2013) that the more households perceive rainwater as important the more the tendency of increasing its rate of adoption increases.

In the case of storage facility size, the model showed a negative association with the adoption of RWHT and size of storage facility. The result was significant at 0.327. The odd ratio of .478 indicates that a unit increase in storage size reduces the adoption of RWHT by .478. The reason for this is that smaller storage facilities dominate in the municipality, although households are eager to harvest more rainwater.

The use of simple technology showed a negative relationship with adoption. However, the result is not statistically significant given the P-value of 0.070 with an odd ratio of 0.137. This was partly because rooftop water harvesting does not require technology that is more complex.

The availability of highly skilled labour in construction of RWHT has a positive link with adoption of RWHT, however, the result is statistically not significant since it has a p-value of 0.748 and odd ratio of 1.340.

Access to rainwater harvesting materials also influences the adoption of the technology. In the model, it has a positive link with adoption of the technology but not statistically significant. Access to rainwater harvesting materials according to the logit model has the probability of increasing adoption by 1.248. Encouragement of households as a strategy to influence their decisions to harvest rainwater has a negative link with adoption. This variable was significant at 0.375 given an odd ratio of 0.071. This implies that mere encouragement without any support cannot increase the rate of adoption of RWHT.

The cost of storage tank increases with it size and this eventually influences the adoption of RWHT. In the model, the cost of tank was significant at .707. The adoption of RWHT is also influenced by the type or kind of treatment given to harvested water in instances where it is meant for potable use. This variable was significant at a p-value of .106 with odd ratio of 3.142 which implies that the kind of treatment increases the rate of adoption by 3.421.

Perception on rainwater quality has a positive link with adoption of the technology. As indicated in the logit model, this variable was significant at .157 and the rate of adoption increases by 12.464, as households perceive rainwater to be of good quality.

Household ownership status had a statistically significant positive relationship with adoption because privately/self-owned households harvest more water as compared to rented households. This is significant at 0.000 and the odd ratio of 13.982 is an indication that privately/self owned household has the probability of increasing adoption by 13.982 than a rented household.

Factors that hinder households from adopting rainwater harvesting

The last specific objective of the study was to determine some factors that influence households' decisions to adopt rainwater-harvesting technology in the municipality. Conversely, the study also sought to find out some possible factors that are likely to deter households from harvesting rainwater in their order of seriousness. When household heads were asked to give possible factors that may likely hinder them from harvesting rainwater in order of seriousness; the following responses were given (Table 23).

Table 23: Factors likely to prevent households from harvesting rainwater

Factors	Frequency	Percentage
High cost of installing a system	76	38.8
Availability of alternative sources of water supply	35	17.9
Evidence of water contamination issues	30	15.3
Inadequate space to keep storage facility	20	10.2
Low or unreliable rainfall pattern	16	8.2
The poor nature of roofs	11	5.6
Lack of technical know-how for system maintenance	8	4.1

N= 196

Source: Fieldwork (2015)

From Table 23, the most predominant factor in this case was lack of finance that has an influence on the cost of installing a harvesting system. Apart from this, availability of alternative sources of water supply was also a major contributing factor. In addition, when the quality of rainwater is not guaranteed as indicated by 15.3 percent of the household heads, this may deter households from adopting the technology. Other factors that hinder households from adopting rainwater harvesting technology as noted by the respondents were; inadequate space to keep storage facility (10.2 percent), low rainfall pattern (8.2 percent), poor nature of roofing material (5.6 percent) and lack of technical know-how for system maintenance (4.1 percent).

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter presents a summary of the findings that emerged from the study on rainwater harvesting in the Adentan Municipality. It also provides conclusions of the study, possible recommendation based on the objectives, and finally suggests possible areas that need to be addressed in further studies.

Summary of the Study

The main objective of the study was to assess rainwater harvesting as a supplement to alternative sources of water supply as a means of addressing perennial water shortages in the Adentan Municipality. Specifically, it assessed the extent of rainwater harvesting; determined the storage capacity required to store rainwater by households; investigated the quality of rainwater; estimated the amount of potential rainwater harvested using rooftops and finally determined factors that influence households' decisions to adopt rainwater harvesting in the Adentan Municipality.

The study adopted the mixed method approach in obtaining data from the field. The data consisted of both spatial (data that is referenced in space) and non-spatial data which was used to obtain household information. The spatial data involved the use of Remote Sensing and Geographical Information Systems techniques in estimating the potential rainwater from rooftops. Econometric analysis (Binary Logistic Regression) was used in determining factors that influence households' decisions to adopt rooftop rainwater harvesting technology. In the case of the non-spatial data, a total number of 196 respondents participated in the study. Out of this number, 98 were adopters of rooftop rainwater harvesting technology whilst 98 were non-adopters. Four key informants were also interviewed of each from the Ministry of Water Resources Works and Housing, Community Water and Sanitation Agency, Ghana Water Company Limited, and the Adentan Municipal Assembly.

Key findings of the study

The main findings that emerged from the study are presented in this section as follows:

1. The main major developmental challenges affecting the Municipality in order of seriousness are limited power supply and inadequate power supply. Developmental challenges identified in the municipality have persisted over many years;
2. In the case of adequate water supply as a challenge in the area, the study showed that although water has being supplied to the Adentan community, access to water still remains a major challenge since water does not run through taps;
3. With regard to how the water challenges have being addressed by stakeholders, more than half of the respondents were of the view that both individuals and the Municipal Assembly are doing well in addressing the problems although some challenges still exist;
4. The socio-demographic characteristics of respondents indicated that out of the total number of household heads who took part in the study,

males constituted more than 50 percent, and most of the respondents were within the youth group of 29-50 years. The survey again showed that the most dominant religions in the Municipality were Christianity and Islamic religions. Most of the people have received formal education in the;

5. On the issue of awareness of rainwater, more than 50 percent of the respondents were aware of rainwater harvesting in the study area. Institutions like the Water Resource Commission, the Community Water and Sanitation Agency, all under the Ministry of Water Resources Works and Housing and the Adentan Municipal Assembly encourage rainwater harvesting at household level;
6. With regard to the extent of rainwater harvesting in the municipality, more than half of both adopters and non-adopters often harvest rainwater. Generally, the study indicated that it was beneficial to harvested rainwater. Majority of respondents agreed that rainwater harvesting should be encouraged in the municipality;
7. The main sources of water supply in order of decreasing importance at Adentan Municipality were pipe borne water, boreholes, water vendors (tanker operators) and rainwater in their ranking. The study showed that households used an average (mean) daily water of about 13 gallons and harvested rainwater was used for both potable and non potable purposes;
8. Rooftop rainwater harvesting was the main technology used in the municipality and the type of storage facilities were plastic and concrete tanks, buckets/barrels, local pots, buckets/pans/barrel, tanks and

reservoirs dominating in the municipality. The estimated average tank size found in the area was 1084 litres. However, majority of the households used storage facilities that ranged between 500 and 1000 litres;

9. In the case of rainwater treatment, the majority of household heads agreed that rainwater should be treated before use. Also, there was no specific method of treating rainwater in the municipality but generally households preferred boiling and filtering respectively to the use of chemicals. In view of this, majority of the respondents assessed the quality of rainwater to be good and this was subsequently confirmed by the water samples test as the values were close to the Ghana Standard Board standards although there was coliform in water samples. This was mainly attributed to birds like vulture, crow sparrows and reptiles like lizards that carry contaminants from refuse damps in urban areas on to roofs. The coliform counts were too high for potable use so treatment is necessary. In view of this, disinfection rate should be done regularly;
10. In estimating the potential rainwater in the municipality, the use of spatial technology has proved to be an efficient decision making tool in solving contemporary problems as in the case of rainwater harvesting. The potential rainwater that can be harvested using rooftops in the Municipality was 33199045.8 m^3 or 33199045800 litres. On monthly basis, June yields the highest potential rainwater of 8177224.4 m^3 and January received the least potential rainwater of 305736.0 m^3; and

11. On the factors that influence households decisions to adopt rainwater harvesting the logistic regression model indicated that, age, sex, marital status, income level, household ownership, the use of simple technology, and government support were statistically significant at 0.05 in explaining household adoption of rainwater harvesting technology in the Adentan Municipality.

Conclusions

Based on the results and findings of this research the following conclusions could be drawn:

1. In the face of recent rural urban migration, increasing urban population growth, emergence of new industries and limited hydroelectric power supply, rainwater harvesting is potentially a sustainable alternative means of supplementing conventional (centralised water supply system) and ensuring water security;
2. Facilities used in storing rainwater ranged from small to larger sizes and form a basic component of rainwater harvesting system. In ideal situation the capacity of storage facilities should be able to store water for four months consumption. However, the capacities of storage facilities found in the study area were much smaller to accommodate all potential rainwater;
3. With regards to rainwater quality, the study concludes that it is of good quality only when it is treated because the test results from water samples revealed some level of coliform; and

4. Factors that influence household decision to adopt rainwater harvesting technology include climatic, social, economic, demographic, technological and attitudinal factors. However, socio-demographic factors proved to be more statistically significant in the study.

Recommendations

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

1. All stakeholders in the water sector should encourage households to substitute rain water for the use of toilet flushing, washing, manufacturing and commercial applications as it has a greater potential of augmenting conventional water supply;
2. Strengthening institutional arrangements and provision of revolving funds by government and other stakeholders in the water sector will increase the decision of households to adopt rainwater as supplementary source of water supply for domestic use;
3. Most of the roofs lack proper gutters especially in Adentan village. Therefore, Planners, city authorities and the department of Works and Housing should encourage households so that rainwater harvesting components especially gutter (conveyance) are incorporated into both old and new buildings so that they can harvest more rainwater;
4. Storage facilities form a major component of rainwater harvesting, the study revealed that most of the storage devices used in the area was at most 1000 litres. However, the storage facility should be able to store potential rainwater for four months consumption.

Therefore, there is the need for households to increase their storage facilities using the potential rainwater from the average roof in the municipality as a reference point;

5. Although, rainwater was found to be of good quality by the respondents, roofs and storage devices should be kept clean regularly by households in the Municipality in order to reduce the coliform to a minimum level. Also, stakeholders related to the Ministry of Water Resources Works and Housing should help households to check and test rainwater quality at least twice a year. Also, the use of first flush diverters and filters should be incorporated in rainwater harvesting tanks to reduce the level of contamination in water;
6. The binary logistic model result on age indicates that young household heads adopt rainwater harvesting technology than old household heads, hence there is a need for policy makers and the private sector to target young household heads in promotion and adoption of RWHT in the area. In addition, the finding on gender that the probability of a male household head adopting rainwater harvesting is higher than that of a female in the logit model clearly suggests the need to develop more suitable strategies for women to encourage them; and
7. Landlords or owners of houses should also endeavor to install rainwater harvesting facilities for their tenants because the model revealed that households in rented houses are less likely to harvest

rainwater because they could be sacked by landlords or relocate at any time.

Areas for further studies

Although water quality was assessed in the study, it was done within a short period due to limited time. Further study could be undertaken with much emphasis on water quality since the quality of rainwater is not static but dynamic. Also another area that needs to be addressed is determination of storage tank size required to store domestic rainwater for individual rooftop in the municipality without using average rooftop.

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APPENDICES

APPENDIX 1

QUESTIONNAIRE/INTERVIEW SCHEDULE FOR HOUSEHOLDS

UNIVERSITY OF CAPE COAST

DEPARTMENT OF GEOGRAPHY AND REGIONAL PLANNING

ASSESSMENT OF RAINWATER HARVESTING IN URBAN GHANA

This questionnaire/Interview schedule is designed for the study of Rainwater Harvesting in Urban Ghana. It seeks to assess Rainwater Harvesting potential as an alternative means of supplementing existing sources of water supply in Adentan Municipality. The findings of this study may contribute to addressing the inadequacies of perennial water shortages in the municipality. Please note that this is merely an academic exercise. Kindly spare me some of your precious time to respond to the questions to the best of your ability and thank you for agreeing to take part in this study.

Section A: General Issues

This section seeks information on general challenges facing the Adentan Municipality

1. Please indicate three (3) major development challenges facing this municipality in order of seriousness

   I. …………………………………………………………………......

   II. …………………………………………………………………......

III. ………………………………………………………………………..

2. How far do you agree that your community has a problem with access to adequate potable water supply? a. Fully Agree [ ] b. Agree[ ] c. Disagree [ ] d. Fully Disagree [ ] e. Undecided [ ]
3. If yes to question 2, how long has this problem persisted in your community? ....
4. How are you as an individual/Assembly addressing this problem?
   I. Individual ……………………………………………………….
   II. Assembly ……………………………………………………….

Section B: The socio-demographic characteristics of respondents

In this section, we will need data on your socio-demographic background. [Please tick [√] where appropriate and write where necessary].

5. Sex a. Male [ ] b. Female [ ]
6. Age of Respondent a. 19 and below [ ] b. 20-29 [ ] c. 30-39 [ ] d. 40-49 [ ] e. 50-59 [ ] f. 60 and above[ ]
7. Marital status a. Single [ ] b. Married [ ] c. Divorced [ ] d. Separated [ ] e. Widowed [ ]
8. Religion. a. Christian [ ] b. Islam [ ] c. Traditional [ ] d. other(s), please specify.……...
9. Level of Education. a. No formal education [ ] b Basic/Middle/JHS [ ] c. Secondary/ "A" Level/SHS [ ] d. Tertiary [ ] e. other, please specify...
10. Occupation of respondent ………………………….............................
11. Household size (Number of people) …………………………………....

Section C: The Extent of Rainwater Harvesting

This part assesses the extent of rainwater harvesting in the municipality by looking at how often water is harvested, demand, storage size and quality of rainwater. Kindly respond to the following questions.

12. I am aware of rainwater harvesting a. Fully Aware [ ] b. Aware [ ] c. Not Aware [ ] d. Not Fully Aware [ ] e. Undecided [ ]
13. I have rainwater harvesting facility (storage tank with gutter or conveyance) installed in my house a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ]
14. How often do you harvest rainwater? a. Very often [ ] b. Often [ ] c. Seldom [ ] d. Never[ ] e. Undecided [ ]
15. Is it beneficial to harvest rainwater? a. Very Beneficial [ ] b. Beneficial [ ] c. Not Beneficial [ ] d. Not very Beneficial [ ] e. Undecided [ ]
16. Do you agree that rainwater harvesting should be encouraged in your locality? a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ]

Water demand

17. What are the main sources of water supply in this community in order of importance? a. wells [ ] b. boreholes [ ] c. pipe borne [ ] d. water vendors [ ] e. rainwater [ ] f. all of the above [ ]
18. How much water does your household use for domestic activities per day? (Amount in Kuffour gallons)……………………………………......

19. In order of importance, what do you use harvested rainwater for? a. Potable uses [ ] b. Non-potable use [ ] c. Both potable and non-potable use
20. What is your average daily expenditure on water? ...…………………......
21. Is the price charge economical to you? a. Very Economical [ ] b. Economical [ ] c. Expensive [ ] d. Very Expensive [ ] e. Undecided [ ]

Water storage

22. Which of the following storage facilities do you use to store harvested rainwater in order of importance? a. Runoff dams [ ] b. tanks/reservoirs [ ] c.buckets/barrels/pans [ ] d. local pots [ ] e. other (please specify)....………………….............
23. What is the size of your storage device (in litres)? ...…………………
24. Do you agree that the cost of acquiring a rainwater storage tank increases with tank size? a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ]. e. Undecided [ ]

Water quality

25. One has to treat rainwater before using it for potable purposes? a. Fully Agree [ ] b. Agree [ ] c. Disagree [ ] d. Fully Disagree [ ] e. Undecided [ ]
26. Which of the following methods of treating rainwater do you prefer in order of importance a. boiling [ ] b. filtering [ ] c. chemicals e.g. alum and chlorine [ ] c. All of the above [ ] d. other(s) (please specify)........

27. How will you rank the quality of harvested rain water? a. very Good [ ] b. Good [ ] c. Bad [ ] d. Very Bad [ ] e. Undecided [ ]

Section D: Other Factors That Influence Households Decisions to Adopt Rainwater Harvesting. This section considers data on some Economic and Technical Factors that influence households' decision to adopt rainwater harvesting technology.

Economic factors

28. Household ownership a. Private or self-owned [ ] b. rented house [ ] c. others, please specify…………………………………...........................
29. What is your average monthly income? (Amount in Ghana Cedis).........
30. How far do you agree that inadequate access to water have negative implications on the economic welfare of your household? a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ]
31. Which of the following main reasons do you think may hinder households from adopting rainwater harvesting technology in order of importance? a. Perception on adequate water supply [ ] b. Financial problem [ ] c. Lack of awareness [ ] d. lack of space for storage facility [ ] e. Others, please specify………………………………….....

Technical factors

To what extent do you agree with the following statements?

32. Getting access to material for installing rainwater harvesting system encourages household to use the technology a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ].

33. The use of simple water harvesting systems enables households to adopt the technology than complex harvesting systems. a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ]
34. Access to highly skilled labour for roof water harvesting system construction influences it use. a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ]
35. Do you think that if government and other non-governmental organisations were to give any assistance in terms of harvesting and installation of system facilities many people will harvest rain water? a. Strongly Agree [ ] b. Agree [ ] c. Disagree [ ] d. Strongly Disagree [ ] e. Undecided [ ]
36. List any three (3) factors that are likely to prevent households' from adopting rainwater harvesting technology in order of seriousness?

    I. ………………………………………………………………

    II. ………………………………………………………………

    III. ………………………………………………………………

Thank You for Your Time and Contributions

APPENDIX 2

IN-DEPTH INTERVIEW GUIDE FOR KEY INFORMANTS

UNIVERSITY OF CAPE COAST

DEPARTMENT OF GEOGRAPHY AND REGIONAL PLANNING

ASSESSMENT OF RAINWATER HARVESTING IN URBAN GHANA

This interview guide is designed for the study of Rainwater Harvesting in Urban Ghana: the case of Adentan municipality. It seeks to assess rainwater Harvesting potential as an alternative means of supplementing existing sources of water supply in Adentan Municipality. The findings of this study may contribute to addressing the inadequacies of perennial water shortages in the municipality. Please note that this is merely an academic exercise. Kindly spare me some of your precious time to respond to the questions to the best of your ability and thank you for agreeing to take part in this study.

Socio-demographic information of respondents

In this section, we would need data on your socio-demographic background. Please provide us with truthful information.

1. Sex
2. Age
3. Place of work (name of institution)
4. Current position occupied at work place

Interview Guide for Key informants in the Adentan Municipal Assembly

1. How do you assess the current state of water situation in this municipality?
2. With the recent extension of the Kpong water supply to this municipality do you think there will be adequate and uninterrupted water supply to meet the demands of everyone in the municipality?

3. What are the key challenges facing the water supply system in the Adentan Municipality?
4. How far have you being addressing the challenges affecting the water supply system?
5. Given the rapid population growth trend and newly developed areas, what is your view on the current water supply in terms of meeting the demands of urban dwellers?
6. Although there is potable water but has not reached the homes of many, what do you think can be done to help solve this problem especially in deprived areas like Adentan village?
7. Do you encourage rainwater harvesting in your municipality?
8. Have you ever encounter any issues of water contamination related to rainwater?
9. What is your opinion on encouraging rainwater harvesting at a municipal scale to supplement conventional water supply as an efficient means of ensuring water security?

Interview Guide for Key informant in the Ministry of Water Resources Works and Housing

1. What roles do you play in terms of the provision of urban water supply?
2. What are some of the policies put in place to help promote access to potable water supply with much emphasis on urban communities?
3. Do you have any policy documents guiding the use and implementation of rainwater harvesting?
4. If there are policy documents, what are they and how are these policies implemented?
5. What are some of the challenges faced by your ministry in terms providing access to water with much emphasis on urban communities?
6. How far has these challenges being addressed?

Interview Guide for Key informant in Ghana Water Company Limited

1. How many litres of water do you currently supply to the entire Adentan municipality?
2. What is the average amount of domestic water consumption per person per day? (Quantity in litres)
3. What accounts for the acute water shortages in this municipality?
4. What are the key challenges that hinder the GWCL from operating at maximum capacity?
5. What is your opinion on rainwater harvesting as a means of supplementing conventional water supplied by the GWCL?
6. Generally, how would you assess the quality of rainwater in the case of potable uses?
7. What are the main sources of contamination that affect rainwater quality?
8. As an expert in the water sector, how can the issues of contamination can be addressed?
9. What other possible safety measures will you recommend for roof water harvesters in order to have clean water?

Interview Guide for Key informant in Community Water and Sanitation Agency

1. What major roles do you play in terms of both urban and rural water supply?
2. Do you encourage rainwater harvesting as part of your responsibilities?
3. In your own opinion, what are some of the specific factors that influence households' decisions to adopt rainwater harvesting Technology? (**Note, consider, Socio-demographic, Economic Attitudinal and Technological factors**)
4. List any three (3) factors that are likely to prevent households' from adopting rainwater harvesting technology in order of seriousness?

Thank You for Your Time and Effort

APPENDIX 3

Monthly rainfall data for the period 1982-2012

Month/Year	January	February	March	April	May	June
1982	0.8	8.9	104.1	93.5	108.9	288.9
1983	0.3	0.0	1.8	42.4	83.9	154.8
1984	0.0	0.0	17.3	50.5	99.2	48.0
1985	0.3	8.1	57.3	14.0	171.7	94.0
1986	0.0	47.3	28.6	27.9	85.5	63.4
1987	24.0	5.2	42.6	45.5	106.4	3.4
1988	0.0	90.1	52.2	77.3	99.4	172.2
1989	0.0	0.0	17.3	142.2	93.4	169.6
1990	1.4	16.0	5.5	79.1	114.8	112.3
1991	5.7	17.3	4.7	174.5	183.4	89.0
1992	0.0	0.0	35.7	35.0	254.3	80.0
1993	0.0	5.9	49.3	61.0	78.8	154.1
1994	9.3	23.7	34.0	37.5	127.4	155.1
1995	0.0	0.2	165.1	97.3	135.8	252.0
1996	0.0	60.7	101.2	291.0	175.2	165.4
1997	0.0	0.0	122.5	177.0	262.3	450.1
1998	0.0	12.6	0.0	12.0	135.4	60.9
1999	29.2	83.2	13.4	55.7	48.8	169.3
2000	0.0	0.0	30.0	39.2	146.8	67.7
2001	0.6	0.0	29.2	168.8	239.7	138.2
2002	39.7	13.0	9.6	175.3	76.8	293.5

Source: Ghana Meteorological Service

Monthly rainfall data for the period 1982-2012 (Continued)

Month/Year	January	February	March	April	May	June
2003	1.0	3.8	44.6	134.1	62.0	309.4
2004	6.5	11.0	13.8	27.1	91.8	55.7
2005	4.4	2.0	184.5	24.6	94.1	147.1
2006	0.0	0.0	34.6	17.5	208.9	167.5
2007	0.0	1.2	66.8	99.7	125.0	260.1
2008	5.2	0.0	89.5	58.4	139.8	77.6
2009	0.0	45.2	5.4	104.7	66.3	289.9
2010	11.6	74.8	60.9	41.2	117.1	276.3
2011	0.6	105.7	2.2	120.6	127.7	177.3
2012	47.9	55.6	57.2	27.4	187.7	111.6
Monthly Total	188.5	691.5	1480.9	2552.0	4048.3	5054.4
Average	6.3	23.1	49.4	85.1	134.9	168.5

Source: Ghana Meteorological Service

Monthly rainfall data for the period 1982-2012 (Continued)

Month/Year	July	August	September	October	November	December
1982	87.2	0.8	0.5	48.0	0.0	0.0
1983	0.0	0.0	47.3	0.0	0.0	0.0
1984	50.3	20.4	79.9	48.9	15.1	31.7
1985	8.6	46.3	23.9	98.2	21.1	0.0
1986	0.8	0.0	5.3	73.2	6.1	29.9
1987	21.2	57.4	297.9	75.7	0.0	14.0
1988	44.8	1.8	72.9	52.4	1.1	65.8
1989	64.9	9.6	15.7	99.5	3.6	0.0
1990	13.1	0.1	39.2	31.5	18.9	111.0
1991	195.2	12.9	23.3	59.1	0.1	0.0
1992	24.5	1.6	4.6	16.3	5.9	0.0
1993	7.2	13.2	61.5	3.4	54.9	23.3
1994	3.7	7.0	14.8	73.5	14.7	0.4
1995	140.2	10.9	1.1	4.5	32.1	55.8
1996	78.8	39.4	10.9	0.8	31.4	0.0
1997	40.5	5.4	0.0	158.2	32.5	46.3
1998	4.7	2.4	6.9	82.7	5.6	11.7
1999	41.7	5.2	28.5	29.7	7.0	3.5
2000	44.7	4.2	3.4	39.9	25.7	15.3
2001	5.4	11.4	105.6	5.1	30.7	6.1
2002	72.0	6.2	37.5	108.4	12.8	0.1

Source: Ghana Meteorological Service

Monthly rainfall data for the period 1982-2012 (Continued)

Month/Year	July	August	September	October	November	December
2003	52.2	8.4	21.6	31.1	26.6	23.6
2004	16.1	31.9	73.6	55.5	24.0	0.0
2005	44.9	1.4	22.7	43.6	41.3	0.2
2006	28.1	6.3	100.8	111.4	0.0	0.0
2007	243.5	38.1	38.4	115.2	52.0	3.0
2008	119.4	31.7	21.7	43.9	29.9	44.6
2009	48.1	10.1	8.1	21.8	0.0	34.4
2010	73.9	28.5	93.2	63.9	93.2	11.7
2011	155.9	6.8	16.2	166.9	12.8	0.0
2012	44.5	4.3	36.8	83.3	0.0	16.5
Monthly Total	1776.1	423.7	1313.8	1845.6	599.1	548.9
Average	59.2	14.1	43.8	61.5	20.0	18.3

Source: Ghana Meteorological Service