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Evaluating Performance of Rainwater Harvesting Technologies in Mwingi Central Sub-County, Kenya

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DECLARATION

I declare that this thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as university supervisors.

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Dr. John P. O. Obiero

Signature: ……………………………… Date: …10-09-2018…

Mr. Stephen C. Ondieki

DEDICATION

I hereby dedicate this research work to my parents, wife, children, brothers and sisters for their affection, love and generous moral support during my studies.

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ABBREVIATIONS AND ACRONYMS

ADRA	Adventist Development and Relief Agency Kenya
ARPN	Asian Research Publishing Network
ASALs	Arid and Semi-Arid Lands
DRYDEP	Dry Land Development Programme
FAO	Food and Agriculture Organization
GHARP	Greater Horn of Africa Rainwater Partnership
GPS	Global Positioning System
ICRAF	International Centre for Research in Agroforestry.
IWRM	Integrated Water Resources Management
KRA	Kenya Rainwater Association
MDGs	Millennium Development Goals
NGAAF	National Government Affirmative Action Fund
NGOs	Non- Governmental Organizations
QGIS	Quantum Geographical Information Systems
RWH	Rainwater Harvesting
RWHT	Rainwater Harvesting Technology
SearNet	Southern and Eastern Africa Rainwater Network
SNV	Netherlands Development Organization
UN	United Nations
UNEP	United Nations Environmental Programme
WVK	World Vision Kenya

ABSTRACT

The purpose of the study was to evaluate the performance of the rainwater harvesting (RWH) systems in the study area. An inventory of existing rainwater harvesting technologies and mapping of key watering points in the study area was conducted through a review of the literature, field observations, and interviews with key informers and administration of a household field questionnaire. The performance of the rooftop RWH systems was evaluated by establishing their technical feasibility, water saving efficiency, reliability ratio, and storage capacity ratio, while the modern demonstration farm ponds were evaluated on reliability only. Economic analysis of both rooftop and pond RWH systems at household level was done to determine their long-term viability through cost-benefit analysis. The research findings were that; Roof catchment systems were the most popular representing about 49% of the rainwater harvesting systems prevalent in the study area. The calculated mean annual household rainwater storage levels was 17. 72m^3. The mean Annual roof runoff in the study area is approximately 76m^3. The mean household water demand in the study area is approximately 40m^3. This is approximately three times more than the current mean household water storage levels. The mean rooftop systems water saving efficiency was 44.85%, and mean reliability ratio of 24.72 categorized under very large deficit, meaning required water is largely higher than supply. The mean storage capacity ratio was 31.89, classified as very critical requirement, that is, the storage capacities are too small relative to the existing potential, this translated to 76.70% of the household rooftop RWHS being classified as of very critical requirement. The modern demonstration farm ponds had a reliability ratio of 1.0125, and were classified as highly sufficient. It was further established that both Rooftop and modern farm ponds RWHS were economically viable with high returns to investments. The research outcomes are a vital source of extra information for policy makers and engineers during the design and execution of RWH technology plans.

CHAPTER ONE

INTRODUCTION

1.1 Background

According to Hudson (1987) Semi-arid areas are defined as regions where the rainfall is a challenge because of amount, distribution, or unpredictability. These regions are characterized by erratic and low rainfall varying from 350 to 700 mm per annum, periodic droughts and different associations of vegetative cover and soils, (Oweis et al., 1999).

Eighty percent (80 %) Kenya’s land is Arid or semi-Arid and this area supports 20% of the country’s population. Arid and Semi-Arid Lands (ASALs) have fragile environment which has potential for degradation as more people and livestock move into them from over- crowded lands of medium and high potential areas. The main problem in ASALs is the seasonal water shortages for domestic, livestock and crop/fodder production. The above is caused by poor rainfall distribution rather than lack of rain itself as up to 50% of rainfall may be lost by run-off while the rest is lost through evaporation. Water harvesting, storage and utilization are therefore key to creation of stable communities in ASAL areas. The annual rainfall in Kenya ranges from 150mm to 2000mm annually, however, the water harvesting technology is underutilized.

The amount of rainfall available for utilization depends on the rate of run-off, evapo-transpiration, the watershed characteristics and methods of interception of various points in the hydrological cycle. Evaporation losses from surface water on land in Kenya range from 120mm to 3000mm per year. Based on the above consideration the potential for rain water harvesting is 42 million m^3 per year. Rain water harvesting is currently practiced in many areas of Kenya; however, the practice has not been expanded to its full potential. The research will contribute to efforts directed at increasing the rural population access to water for domestic, livestock watering and even small-scale irrigation.

Numerous small-scale farmers in Kenya are food insecure due to their long-time dependency on rain fed agriculture. Most of the Kenya ASALs receive unreliable rainfall, the intensity and spread of the rainfall season is usually quite variable resulting in low crop and livestock production levels. Efforts aimed at enhancing the performance of rainwater harvesting systems can play a major role in improvement of the livelihoods of the rural communities. Rainwater harvesting interventions can greatly contribute to water and food security in the ASALs. Rainwater harvesting is the harnessing of rainwater from a catchment for storage in tanks or percolation into the soil (Mati *et al.* 2006). A farm pond of approximately 1000 m^3 full of runoff water can be utilized for farming nearly half an acre of land (Senay and Verdin, 2004).

1.2 Problem Statement

Like it is the case in Ethiopia (Girma, 2009) for quite a long period, the Kenyan government in close collaboration and partnership with NGOs has been involved in promotion of Rainwater harvesting (RWH) to enhance water accessibility for both domestic and agricultural use. However, the implementation of the rainwater harvesting technologies has faced a lot of challenges and its uptake is low. Many of the implemented rainwater harvesting structures do not perform as envisaged in harvesting and storage of sufficient volumes of runoff to address the water needs mainly for domestic, livestock and crop production. The main cause of this undesired scenario is that there is insufficient structural design considerations of the rainwater harvesting systems (Alamerew, 2006). In Kenya today, implementation of rainwater harvesting systems are carried out without due consideration of technical aspects. A more organized approach to the design, installation and construction of RWH interventions will go a long way to improve their performance and adoption rate.

1.3 Objectives of the Study

The main objective of the study was to evaluate the performance of the existing RWH systems in order to assess their contributions to water security in Mwingi Central sub county, Kitui County, Kenya.

Specific Objectives

1. To identify existing rainwater harvesting technologies in the study area and map key watering points by physical and social assessment.
2. To evaluate technical performance of rooftop and farm pond rainwater harvesting technologies in the study area.
3. To establish economic viability of rooftop and farm pond water harvesting technologies addressed in (ii) above.

1.4 Justification

Water is an essential commodity that is required by every living thing. In the Kitui County integrated Development plan (CIDP), 2013-2017, planning for sustainable social-economic growth and development, the water sub-sector has been cited as one of the main development challenges in the County. Kitui County is ranked among the counties in the country experiencing acute shortage of clean and safe water.

During the long dry spells, the shallow wells and the streams dry up and the main water source becomes the deep wells which are risky and unreliable. This translates to high costs of living by the inhabitants as the time and some of the money used on water could have been channeled to other economic ventures. The water is transported using human labour by mainly women and school going children, hand carts, wheelbarrows, bicycles, motorbikes, and donkeys.

This study is therefore relevant for it addresses; Sustainable Development Goals (SDGs), Kenya Vision 2030, and the countries big four economic development agenda.

Under Sustainable Development Goals (SDGs), the study addressed issues highlighted under, Goal one (1), two (2) and six (6), which focus on aspects concerning, poverty status, hunger, food insecurity, sustainable agriculture and water security by the year 2030.

For Kenya Vision 2030, the study addressed issues concerning, economic (Promoting household agricultural growth), social (Water & sanitation - water harvesting & storage), and Political Pillars.

While in respect to “The Big Four (4) Agenda / pillars” or Vision for economic development in Kenya by year 2022, the study is relevant for water resources are essential in promoting, food and nutrition security, affordable housing, manufacturing and enhancing affordable healthcare.

The research contributes to efforts directed at increasing the rural population access to water for domestic, livestock watering and even small-scale irrigation.

1.5 Hypothesis

1. The existing rain water harvesting systems are not producing significant impact.
2. Existing RWH systems are performing poorly.
3. Potential for RWH in the study area has not been fully realized.
4. RWHS practiced in the study area are perceived to be characterized by low productivity.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter offers a summary of the various forms of rainwater harvesting technologies commonly practiced in ASAL environments. It also provides an insight on the state of the efforts aimed at promoting rainwater systems implementation in Kenya, and the various key players involved in implementation of rainwater harvesting technologies. Further, the chapter also gives a brief description of the relevant mathematical models relevant in evaluation of the performance of rainwater harvesting technologies. The performance evaluation criteria, parameters and research gaps are also highlighted.

2.2 Rainwater Harvesting

Rainwater harvesting is broadly defined as the collection and concentration of runoff for productive purposes such as crop, fodder, pasture or trees production, livestock and domestic water supply in arid and semi-arid regions (Gould, 1999; Stott, 2001; Fentaw et al., 2002). For agriculture purposes, it is recognized as a method for inducing, collecting, storing and conserving local surface runoff in arid and semi-arid regions; in order to mitigate the effects of temporal shortages of rain (Oweis et al., 1999; Prienz & Singh, 2001).

Rainwater harvesting is used as a climate adaptation strategy that has been in use during many eras of mankind. Archaeological studies and historical information showed that the technology was in use for more than 10,000 years on all continents. In most cases it was mainly used as an alternative water source in dry periods and it was a survival strategy for ancient civilisations (Hofman & Paalman, 2014). It is an ancient practice and still forms an important part of many farming systems worldwide.

2.3 Popular Rainwater Harvesting Technologies in ASAL Environments

The most commonly implemented rainwater harvesting technologies in ASAL environments of Kenya are; subsurface dams/sand dams, rooftop catchment systems, shallow wells, rock catchments, water pans, earthen dams and water ponds (Aroka, 2010).

The plates below are pictures of some of rainwater harvesting structures within the study area;

2.3.1 Rock Catchments

This is a rainwater harvesting system of directing runoff from rock catchment surfaces into reservoirs by construction of stone barriers or walls. Water can be conveyed by gravity to storage tanks and then supplied to the community watering kiosks.

Plate1: Kiaa rock catchment

2.3.2 Sand Dams / Subsurface Dams

Sand dams /subsurface dams are usually constructed across a dry river bed to hold back the river sand which eventually acts as the storage for part of the runoff water and exploited during the dry spells after the rains by scooping shallow wells downstream of the erected dam wall to access the water for domestic and livestock watering (Nissen-petersen, 2006).

Plate 2: Mathungi sand dam

2.3.3 Farm Pond and Pans

With appropriately selected catchment sites, pans and farm ponds are dug up to capture and store runoff from surfaces such as hillside, roads, rocky areas and open range lands. However, pans and ponds have their own limitations. These challenges include; their relatively small capacities, high rates of silting, loss of water through seepage and high evaporation losses (Mati et al, 2005). Modern farm ponds have systems put in place to control water losses through seepage and evaporation. This is achieved through incorporation of a dam liner and evaporation control net in the design of farm ponds.

Plate 3: Unlined farm pond/pan

Plate 4: Modern lined farm pond

2.3.4 Roof Catchment Systems

Roof catchment systems comprise a storage tank (ranging from15-150 m^3), a roof, which is in this case the catchment's surface, and guttering system, including a simple foul-flash component to trap the first flush of dirty water before it enters the storage tank (Ngigi et al, 2005a). Roof catchments systems rainwater is the easiest to access, most dependable, and least contaminated water source. It can be well managed at household level for it is less prone to abuse by outsiders (Arun & Sudhir, 2009).

Plate 5: Household rooftop water harvesting (reinforced concrete tank)

Plate7: Household rooftop water harvesting (plastic tank)

2.3.5 Shallow Wells

Hand-dug wells ranging from less than a meter deep to 15 meters deep are usually constructed in areas with relatively high-water table or at dry river beds. These are usually the most popular watering points for the people living in ASAL environments. Water lifting through use of hand or motorized water pump is usually a common practice to draw water for both domestic and small-scale irrigation purposes.

Plate 8: Shallow well equipped with a hand pump

Plate 9: Shallow well dug at a dry river bed, with a water pump, and adjacent farm plot is under irrigation

2.3.6 Earth Dams / Pans

Earthen dams are usually constructed across seasonal river valleys or water ways. Their design requires involvement of qualified professionals, and usually their cost is high, and this calls for support from government and other development partners to fund construction of the earth dams. However, some communities in ASAL environments have united and manually constructed their own earthen dams. These structures are usually faced with challenges of water contamination and high siltation rates as a result of human activities in the catchment areas.

Plate 10: Kasovi earth dam

2.4 Rainwater Harvesting Interventions in Kenya

Over the years the Kenyan government in partnership with development partners has been implementing policies aimed at promoting rainwater harvesting in Arid and Semi-Arid lands. Through her state departments of agriculture, livestock, water and irrigation, state corporations like the Kenya water and pipeline company, Kenya has implemented many rainwater harvesting structures. Key intervention measures in partnership with development partners are construction of water dams across major rivers, earth dams and water pans construction and promoting of construction of farm ponds for enhancement of food security through water harvesting at household level. Rainwater harvesting is more economical if compared to other conventional methods of water supply.

Christian based organizations like Caritas, ACK, Salvation army, world vision Kenya have supported in funding roof water tanks for schools and construction of water pans and earth dams for use by the rural communities living in water scarce environments. Other non-governmental organizations promoting rainwater harvesting in Kenya are ADRA Kenya and Kenya Rainwater Association among many others. The private sector has been involved through manufacture of the necessary infrastructure materials needed to implement rainwater harvesting projects such as gutters, roofing material, and water tanks.

Presently the Kenyan government and stakeholders are implementing construction of water ponds for demonstration and uptake by the community through the recently launched Kenya chapter of the Billion Dollar Alliance for Rainwater Harvesting, a continent-wide, multi-actor alliance designed to scale up farm pond technology for agribusiness and livelihood resilience for dryland farming systems (ICRAF).

The County governments in ASALs each year set aside development funds for construction of earth dams, water pans, farm ponds and subsurface and sand dams and for drilling of community boreholes. There have been success stories in uptake of farm ponds in Lare division, Nakuru County and also in Yatta District, Machakos county (Malesu et al., 2006.)

However, there are numerous limitations/shortcomings associated with the existing RWH interventions with regard to the appropriateness of their designs or economic viability. Most of the structures lack requisite facilities like silt traps, animal watering troughs and fencing. The catchment areas are not protected and are therefore polluted by human activities. The structures also loose a lot of water due to high seepage and evaporation rates. Moreover, Lack of economic diversification in utilization of the stored water, leads to long pay back periods on investments incurred. This has consequently resulted in to low replication of the RWH interventions by the targeted beneficiaries.

2.5 Rainwater Harvesting Models

2.5.1 Roof Model

According to (Kahinda, et al., 2010), Roof mathematical model calculates the desired household tank volume when day-to-day water usage and roof catchment area are well-known.

Roof runoff is therefore calculated by using the below mathematical model:

$$Q = P. A .C \qquad (1)$$

Where Q = roof runoff into the tank in cubic meters per day,

P = precipitation in meters per day,

A = roof area in square meters and

C = roof runoff coefficient.

2.5.2 Runoff Model

The runoff model expresses catchment yield or runoff volume as a function of precipitation, and the catchment area. This mathematical model computes the translation of rainfall into runoff (Huizing, 1988).

The catchment water yield depends on rainfall characteristics; amount and reliability and the catchment characteristics; vegetation type, soils, size, slope. The quantity of runoff generated from catchment depends on how much precipitation is lost on the catchment through depression storage, infiltration and evaporation. The problem of predicting surface runoff is very complicated. A lot of research work has been carried out on different methods of estimating the runoff generated from a given area.

The methods range from simplistic models relating runoff to catchment area and return period, to highly complex mathematical models which take into considerations a large number of catchment parameters, and are only solvable with the use of computers. The latter approach has its drawbacks as it requires a very good basic data bank, climatological, hydrological, geological and agricultural data that is often not available (Finkel and Finkel, 1986). In these circumstances, the simple empirical rules of the thumb are used to give an estimate of the design runoff.

Runoff coefficient

The collection of rainwater is usually represented by a runoff coefficient. The 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. A runoff coefficient of 0.85 means that 85% of the rainfall will be collected. So, the higher the runoff coefficient, the more the rainwater that will be collected (Biswas & Mandal, 2014).

The total runoff from a given catchment can be assumed to be equal to the volume of precipitation falling on the catchment reduced by a runoff coefficient (UNEP, 1983). This can be expressed mathematically as:

$$V = P \, . \, C. \, A \qquad (2)$$

Where;

V = Runoff volume in cubic meters

P = Precipitation in meters

C = Runoff coefficient

A = Catchment area in square meters

Runoff Calculation

Runoff is one of the most significant variables used in the planning of water resources and water quality management. Numerous approaches to calculate runoff from a precipitation incident have been developed since the first extensively used rainfall-runoff model suggested by the Irish engineer Thomas James Mulvaney in 1851. One of the common approaches for estimating the surface runoff volume from a rainstorm from small watershed is the Soil Conservation Curve Number (SCS-CN) approach which was developed by the Soil Conservation Service (now called the Natural Resources Conservation Service, NRCS) of the United States Department of Agriculture (USDA) in 1954 (Mariappan,1990). The SCS-CN method translates precipitation into surface runoff using its parameter Curve Number (CN) which symbolizes the runoff potential of a watershed characterized hydrologic soil category, land use form and treatment, ground surface situation and antecedent moisture condition (AMC). The SCS-CN method comprises of the following equations:

$$P = Ia + F + Q \qquad (3)$$

$$Q/(P - Ia) = (F/S) \qquad (4)$$

$$Ia = \lambda \times S$$

Where P= total rainfall, Ia=initial abstraction, F= cumulative infiltration excluding Ia, S=potential maximum retention or infiltration.

S can be estimated by

$S = (25400 / CN) - 254$ (5)

Therefore runoff per unit area is determined to assess the inflow into a water pond.

2.5.3 Water Balance Model

In hydrology, a **water balance** equation can be used to describe the flow of water in and out of a system. A system can be one of several hydrological domains, such as a column of soil or a drainage basin

A general water balance equation is:

$P = R + E + \Delta S$ (6)

Where;

P is precipitation

E is evapotranspiration

R is stream flow

ΔS is the change in storage (in soil or the bedrock / ground water)

This equation uses the principles of conservation of mass in a closed system, whereby any water entering a system (via precipitation), must be transferred into either evaporation, surface runoff (eventually reaching the channel and leaving in the form of river discharge), or stored in the ground. This equation requires the system to be closed, and where it isn't (for example when surface runoff contributes to a different basin), this must be considered.

A water balance can be used to help manage water supply and predict where there may be water shortages.

2.6 Precipitation Analysis

An area’s rainfall plays the guiding factor in designing rainwater harvesting systems and examining their effectiveness. Both the total annual rainfall and the distribution of that rainfall throughout the year must be considered in the evaluation and design of a rainwater collection system. Due to the inherent unpredictability of rainfall patterns, a long-term record of precipitation (ten years or more) is recommended for use in designing a rainwater harvesting system (Martin, 2009).

Statistical Analysis of Data

The statistical behavior of any hydrological series can be described on the basis of certain parameters, generally mean, variance, standard deviation, coefficient of variation and coefficient of skewness are taken as measures of variability of any hydrologic series. According to one source, the recommended minimum amount of rain required for a RWH system is 50mm per month for at least half the year

(Development Technology Unit, 1987). Another source recommends 400mm per year (United Nations Environmental Programme, 1997).

2.7 Economic Analysis of Rainwater Harvesting Systems

An important factor in utilizing rainwater is the economic viability of the system. Although RWH may bring more sustainability to a community, it should also be a cost-effective solution. Economic evaluations have been done by many different approaches in the water sector, including cost-benefit analysis, net present value, internal rate of return, or payback time (Hofman & Paalman, 2014). Enhancement of rainwater harvesting through implementation of RWH technologies is a venture where a farmer spends money and related assets into a rainwater harvesting system with an aim of gaining paybacks overtime. Therefore, a benefit to cost examination is critical in accessing the cost-effectiveness of implementation of RWH systems (Ngigi, et al., 2005b).

Tam et al. (2010) suggested that the biggest consideration in the decision whether to install a RWH system lies in terms of financial costs and benefits, remaining the issues about public acceptability and water quality in the background. For this reason, it is particularly important to determine the economic feasibility of RWH systems.

2.8 Design of RWHS

The major design criteria for RWHS are the hydrologic and economic criteria. Before designing a project, it may be necessary to undertake a study of what priorities and socioeconomic variables are necessary to increase the adoption rate of rainwater harvesting technique by farmers. It is necessary to compare design options using cost benefit analysis. However, the measure of benefits may be difficult and it may not be possible to measure all the benefits which can be expected to result from the project (UNEP, 1983).

The economic approach is to find the least cost solution to supply the estimated demand for water. An excessively large reservoir would represent a wasted economic resource and reservoir too small cannot meet the desired water demands and therefore proper sizing is important (Palmer, et al., 1982b).

There are three approaches commonly used to determine a hydrologic design value namely, empirical approach, risk analysis and hydro-economic analysis (Chow *et al.,* 1988). A proper design of storage system would involve:

- Hydrologic analysis including probability of occurrence of runoff, rainfall reliability and distribution;
- Hydraulic design to determine physical sizes of the tanks and ponds considering water demand, available catchment area, seepage and evaporation losses;
- Management of stored water

- Desired system reliability and efficiency and
- Economic viability of the system.

The factors that control the performance of a RWHS are;

- The amount and distribution of rainfall;
- The runoff coefficient of the collecting surface;
- The size of the catchment;
- The reservoir storage provided;
- The amount and distribution of the demand; and
- Evaporation and seepage losses.

2.9 Performance Evaluation Techniques for RWHS

The most commonly used rainwater harvesting evaluation criteria or parameters according to (Adham, et al., 2016) are;

i. Reliability – the percentage of days that the demand is met or the proportion of demands that are met

ii. Water saving Efficiency

iii. Economic – benefit cost ratio evaluation

iv. Effectiveness - in runoff capture

v. Sustainability – social acceptance, water quality and maintenance needs

vi. Environmental impact

vii. Technical feasibility (considering seasonal rainfall and roof area sizes)

viii. On farm utilization

The appropriate design and evaluation of a RWH system is necessary to improve system performance and the stability of water supply. The main design parameters of a RWH system are rainfall, catchment area, collection efficiency, tank volume, and water demand (Mun & Han, 2012).

Water balance modelling is applied to determine water saving efficiency. The performance of rainwater collector depends on the size of the collection system. Behavioral model uses a mass–balance transfer principle and are based upon a discrete time interval of a minute, hour, a day or month (Fewkes & Warm ,2000).

The effectiveness of rainwater collection systems have been examined using behavioural model. Where the performance of a rainwater collection system was evaluated relative to its water saving efficiency which is given as (ET). This is the amount of water that has been conserved in the mains in comparison to the overall demand of water (Olaoye, et al., 2013).

Water saving efficiency is usually expressed as a percentage, which is given as:

$$ET = \sum Yt / Dt \times 100 \qquad (7)$$

Where;

ET is Water saving efficiency at time t

Yt is Yield (m^3)

Dt is Demand (m^3)

For this study evaluation of the performance of rooftop RWHS was achieved through establishment of their technical feasibility, reliability, and water saving efficiency, while for farm ponds establishment of their reliability was sufficient parameter for decision making. These evaluation parameters were found to be satisfactory in drawing opinions and conclusions on RWHS performance levels.

2.10. Data Collection Tools

For purposes of evaluating the performance of rainwater harvesting systems, questionnaires targeting individuals' household heads and key informers' interview are key for primary data collection. Review of existing literature and physical observation can help in gathering secondary data.

2.11. Conclusions of Reviewed Literature

Rainwater harvesting system mainly entails collection and subsequent use of captured rainwater as either the principal or supplementary source of water. All rainwater harvesting systems share a number of common elements:

i. A catchment's surface from which runoff is collected e.g. roof surface.

ii. A system for conveying water from the catchment's surface to a storage reservoir, known as the delivery systems.

iii. A reservoir or a storage system where the harvested water is stored.

iv. A means of lifting the water from the reservoir.

The extensive application of rainwater harvesting projects is limited by the challenge posed by the un predictable dry seasons. Increased water demand overtime has generated increased interest in RWH systems. RWH is considered as part of sustainable development and rainwater is a naturally occurring and potentially clean source of water. There is little research on the economic analysis of RWHS in developing countries. There are concerns over the environmental impacts of storm water runoff. RWH tank sizes can be increased to compensate for reduced reliability. This study will focus on reliability and economic analysis of both rooftop RWHS and farm ponds. Investing in a RWHS has very low risks and will most likely have short pay back times. RWH is part of solution to mitigate water scarcity problem in semi-arid environments. Challenges of RWH development are, environmental, policy, economy, social and technical. In order to promote RWH in Kenya, interministerial and multi- stakeholders co – operations are needed to mainstream this alternative water resource into the national strategy.

Limitations in the Present RWH Technologies

For RWH to be reliable and economically viable, it should be based on appropriate design, operation and maintenance. Although rainwater harvesting techniques have been extensively used for a long time and much written about the subjects, there is little information available on water harvesting in Sub-Saharan

Africa and whatever information there is has not been collected or analyzed systematically (Reij, et al., 1988).

There is little data available on design and almost nothing on water management and most systems are installed on the basis of local folklore (Bazza and Tayaa, 1994). In most cases there is no integrated study prior to the construction of the systems and hence the techniques applied are inappropriate and do not suit the environmental conditions.

The storage systems face water loss problems through evaporation and seepage. The seepage losses occur since the storage systems are not lined with any protective materials or roofed. In addition to the technical defect, water harvesting projects have rarely been monitored or evaluated to assess the degree and causes of success or failure. As a result, subsequent projects are planned in the same way with all the previous errors and without any benefit from past experiences.

Identified Research Gaps

ASALs around the Earth face water inadequacy due to low amounts of precipitation and irregular rainfall seasons. For quite a long time, RWH technologies have been used to manage water shortage. Scholars have used many diverse approaches to identify appropriate locations and methods for RWH. Nevertheless, narrow consideration has been directed to the assessment of RWH systems performance (Adham et al, 2016).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area – Brief Description

Mwingi Central sub county is located in Kitui County, Kenya and is classified as ASAL; soils are mainly sandy with pockets of black cotton soils and alluvials. It receives 300 to 1000 mm of rainfall, bimodal, with “Short rains” October to December being more reliable than the “Long rains”, March to May. It lies in **Agro - ecological zones**: Lower Midland 5 (LM_5) Livestock-millet zone. Most of the small-scale farmers depend on seasonal rivers to fetch water for both domestic and livestock watering. The area is characterized by high evaporation rates due to the hot and dry weather conditions. Farmers here practice mixed crop and livestock farming. The main livestock being cows, goats, sheep and local poultry and the main crops being pigeon peas, green grams, cowpeas, millet and sorghum.

Mwingi central sub county is subdivided into 14 locations; namely Mwingi, Kavuvwani, Kiomo, Kairungu, Kyethani, Mwambui, Waita, Endui, Enziu, Kivou, Kanzanzu, Mumbuni and Kisovo Location. The Locations are further subdivided into 34 sublocations.

Kavuvwani location has a total population of 17,537 persons and is divided in to three sublocations namely, Kavuvwani sublocation, Kavuoni sublocation and Mwingi central sublocation. Kavuvwani sublocation has 2224 households, while

Kavuoni sublocation has 2673 households and Mwingi central sublocation has 820 households.

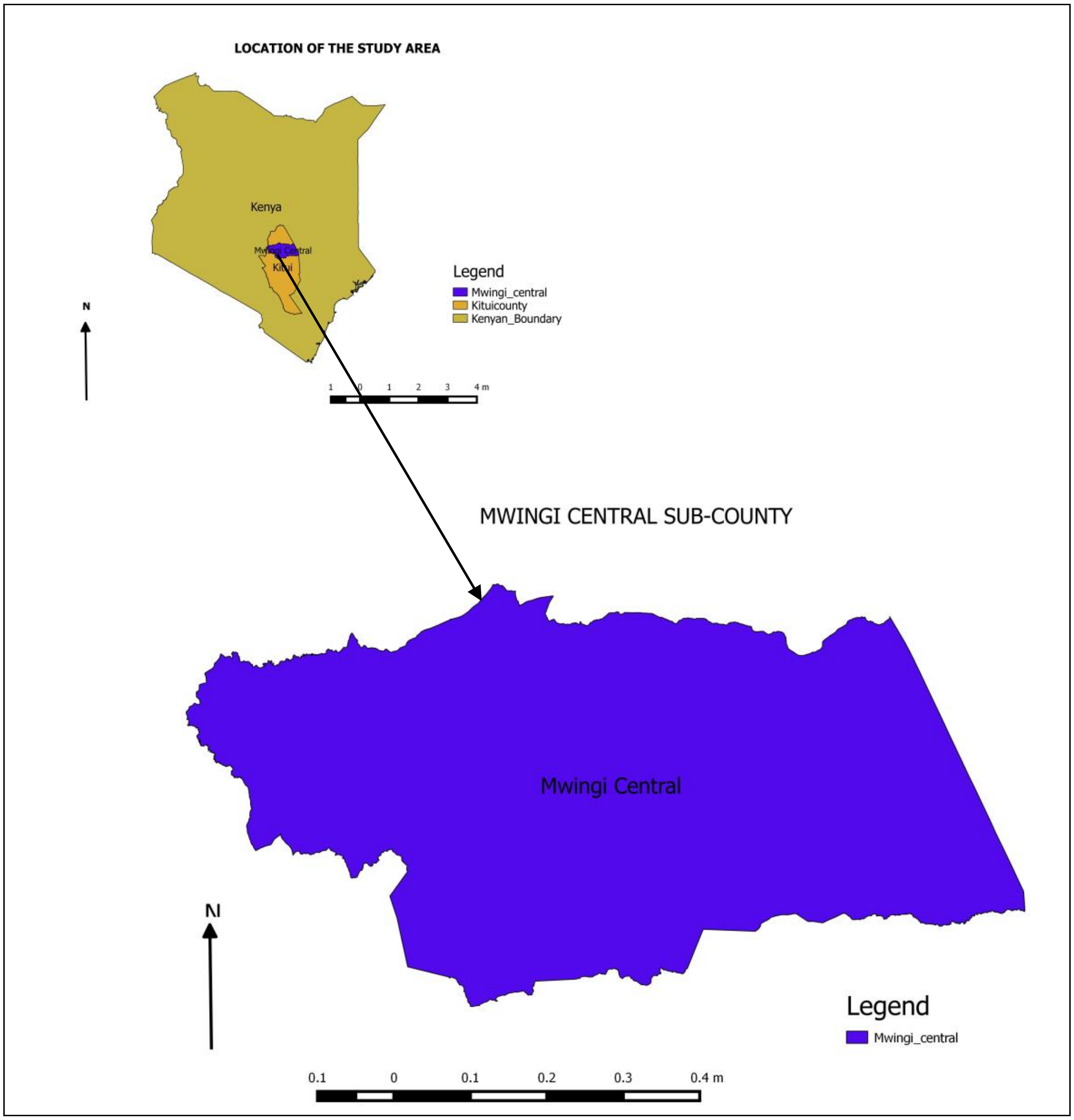


Figure 3.1: Study Area Location Map

3.2 Data Collection /Requirements

3.2.1 Identification of Existing Rainwater Harvesting Technologies

A physical and social assessment involved taking account of the current situation (situational analysis). This comprised of taking inventory of existing water resources, getting information on whether the water sources were for potable or non-potable uses. The current conditions of the water resources were evaluated. Information on water resources accessibility to the community was also key. More information was collected on the water sources reliability. Preference of some water sources to others was also cross-examined. Reasons as to why the community does not practice some rainwater harvesting technologies were sourced from key informers. An inventory of existing rainwater harvesting technologies in the study area was done by gathering information from key informants, physical observation, review of the existing secondary data and also by administration of a household-based questionnaire. A sample of the questionnaire is appended (Appendix A).

Sample Size Determination

The sample size was determined using proportional probability to population formula. For populations that are large, the Cochran (1977) equation, illustrated below yields a representative sample for proportions.

$$n_0 = \frac{Z^2pq}{e^2} \tag{8}$$

Where;

n_0 is the sample size,

Z is the selected critical value of anticipated confidence level,

e is the sampling error,

p is the estimated proportion of an attribute that is present in the population while

$q = 1-p$.

From statistical tables $Z = 1.96$ for 95 % level of confidence

If sample proportion is not given, use, $p = 0.5$ as a conservative estimate in formula for sample size involving proportion. Assume sampling error; $e = 0.08$

Using; $p = 0.5$, hence $q = 1-0.5 = 0.5$; $e = 0.08$; $z = 1.96$, therefore $n_o = 150.0625$

A total of 150 household respondents were interviewed. The target population for data collection included key stakeholders like; Farmers at household level, Agricultural office personnel, Area Chief and Sub-Chiefs, self-help groups, and NGO's involved in water harvesting interventions. Using simple random sampling three sub-location, (Kavuvwani, Kavuoni and Mwingi Central) were selected for the study conducted at village level targeting household heads as the respondents. Data on major watering points per sub location was provided by area sub chief and GPS Coordinates for mapping of key community watering points was collected using a GPS coordinates tool in the smart phone and analyzed through use of QGIS software. Two more enumerators were inducted on the data collection tool, were supervised on data collection during pretesting of the tool before approval for field data collection. They therefore assisted in household questionnaire administration.

To assess the technical effectiveness of the diverse rainwater harvesting systems the following aspects were considered; siltation, water use, catchment conditions (vegetation cover, human activities and catchment area), and forms of water loss from the reservoir. Data was collected covering the following attributes, volume of the reservoirs, catchment characteristics, use of the stored water, sedimentation levels, and incorporation of silt traps, fencing and water draw off point in the design. In particular data was gathered to capture;

i. Popular Rainwater harvesting systems
ii. mapping of major watering points and their respective attributes
iii. Identify key stakeholders involved in implementation of RWHS
iv. Identify key challenges and limitations of existing watering points
v. Identify practiced RWHT at household level
vi. Identify main causes of low adoption of RWHT at household level
vii. Rating of household level water availability
viii. Identify major types of RWH storage tanks in the study area

3.2.2 Evaluation of Technical Performance of Selected RWH Systems

The technical performance of rooftop, and farm pond water harvesting structures was evaluated by comparison of existing designs with the expected or theoretical designs. The evaluation criteria adopted was on,

i. Assessment of technical feasibility. Rainfall is one of the major components in any RWH system, with the amount of rainfall playing a major role in evaluating the RWH suitability for a given area. In arid and semi–arid regions, precipitation varies significantly in time and space. RWH systems can only function if there is adequate rainfall in the catchment area to be stored in some way. Yearly precipitation of above 325mm is considered as having high potentials of harvesting part of it and categorized as greatly suitable. One of the key principles of RWH is storing water to moderate drought effects in dry spells. In principle, the volume of water harvested and the quantity retained over a rational period of time is one indicator of the performance of RWH system. This calls for establishment of existing storage capacities and the desired storage capacities.

ii. Reliability – The relationship between the demand and supply of water (reliability) is a good indicator of the performance of a RWH structure. That is, how well the RWHS satisfy the water demand. Reliability ratio evaluates demand versus supply. The ratio between the total demand and the total supply of water. High suitability scores for the ratio are close to one.

iii. Water saving efficiency - This is the amount of water that has been preserved in the mains in comparison to the overall demand of water. It is appropriate to determine the percentage of the water saving efficiency of each storage because this will support in knowing how sufficient a given capacity can fulfill a given demand, and

iv. Storage capacity ratio - The ratio between the total volume of water inflow and current storage capacity. The ratio that is close to one is rated as greatly suitable.

(a) Roof Water Harvesting Systems

Data collected per household captured the following parameters

i. Roof area,

ii. family size,

iii. storage capacities, and

iv. water use.

Other data requirements were;

- Precipitation data- (collected from meteorological station within the study area)

- Roof runoff coefficient (used 0.85 for this study)

(b) On Farm Water Harvesting Systems

During collection of primary data through administration of the household-based questionnaire and also through physical observations, the key aspects under consideration were forms of on farm water harvesting storage systems in place. Parameters under consideration were;

1. farm pond capacities,
2. pond water catchment sizes or source of the farm pond water,
3. technical design aspects like lining of the ponds to control seepage, covering with evaporation control nets,
4. type of water lifting system used to draw water from the pond,
5. incorporation of silt traps,
6. fencing of the ponds and
7. usage of the pond water.

3.2.3 Cost Benefit Analysis for Rain Water Harvesting Systems

To determine the cost effectiveness of the rooftop and farm pond RWH structures and systems, it was necessary to collect data on cost of construction, purchase or installation of the systems, the costs of operation and maintenance, the life span of the rainwater harvesting storage systems, quantity of harvested water and equivalent monetary value of quantity of harvested water if it was to be purchased from a water vendor in the study area. Also, data was collected on any other beneficial use of the stored water like small scale irrigation or kitchen gardening.

3.3 Methods of Analysis

3.3.1 Identification of Water Harvesting Technologies

Data was gathered on, popular types, and number of Rainwater harvesting systems, GPS coordinates of major watering points and their respective attributes of Name of the watering point, Volume or storage capacities of the RWHS, and generally physically observable status of the key communal watering points. Other data collected was on, key stakeholders involved in implementation of RWHS, key challenges and limitations of existing watering points, practiced RWH technologies at household level, main causes of low adoption of RWH technologies at household level, rating of household water availability levels, and major types of RWH storage tanks in the study area. This data was analysed using SPPS and excel softwares and was expressed in form of bar charts, pie charts and frequency tables. GPS mapping of major water points was processed using QGIS software.

3.3.2 Evaluation of Technical Performance of Selected RWH Systems

3.3.2.1 Precipitation Analysis

To determine the area rainfall unpredictability, statistical analysis was performed on rainfall data acquired from Mwingi central agricultural meteorological station (registration number 9038008), appended in (appendix B). The rainfall data collected spread for over about thirty years. Parameters determined were standard deviation mean yearly and mean monthly precipitation and over-all variability over yearly and monthly period.

3.3.2.2 Performance Evaluation Analysis

This was achieved by considering the ideal designs with the actual designs. Roof model and mathematical rain-runoff models were used. Volumes of water harvested were compared with volumes of water expected to have been harvested using the existing area of the catchments. Parameters used in the evaluation were technical feasibility, reliability ratio, water saving efficiency, and storage capacity ratio and were determined for each RWHS under consideration. However, for farm ponds only reliability was determined. The gathered data was analyzed using both SPSS and Excel software.

3.3.3 Cost Benefit Analysis of Rainwater Harvesting Structures

Benefits and costs associated with water projects occur at various times. Initial investment costs occurring at the beginning of the project life are associated with construction or implementation. Operation and maintenance costs continue throughout the life of the project. To achieve this objective the, Benefit Cost Ratio, Net Present Value and Internal Rate of Return, were applied.

Equation

$$A = P\left(\frac{i(1 + i)^N}{(1 + i)^N - 1}\right) \qquad (9)$$

The above discounting formula convert cash flows between a present amount P, and uniform annual series A. The factors within the parenthesis are a function of the annual interest or discount rate i and number of compounding periods (Years) N. This Mathematical Model was expressed in an Excel sheet for purposes of analyzing the collected data on cost of construction, purchase or installation of the RWH systems, the costs of operation and maintenance, the life span of the rainwater harvesting storage systems, quantity of harvested water and equivalent monetary value of quantity of harvested water if it was to be purchased from a water vendor in the study area and any other economic benefit derived as a result of use of the harvested rainwater, calculations of annual series and respective benefits gained as a result of investment in RWH systems were done and comparatively analyzed using excel software, and results expressed in form of bar charts for easy interpretation.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Rain Water Harvesting Systems Practiced in the Study Area

Rainwater harvesting systems practiced in the study area are; Roof catchment tanks, farm ponds, water pans, shallow wells, sub-surface dams / sand dams, Rock catchments and boreholes.

Table 4.1: Practiced Water Harvesting Techniques

Frequency Table

Water Harvesting Technologies	Frequency	Percent	Cumulative Percent
Roof Catchment Tanks	45	48.9	48.9
Farm Ponds	12	13.0	62.0
Water Pans /Earthdams	6	6.5	68.5
Shallow Wells	14	15.2	83.7
sub-surface dams / sand dams	6	6.5	90.2
Rock catchments	3	3.3	93.5
Boreholes	6	6.5	100.0
Total	92	100.0	

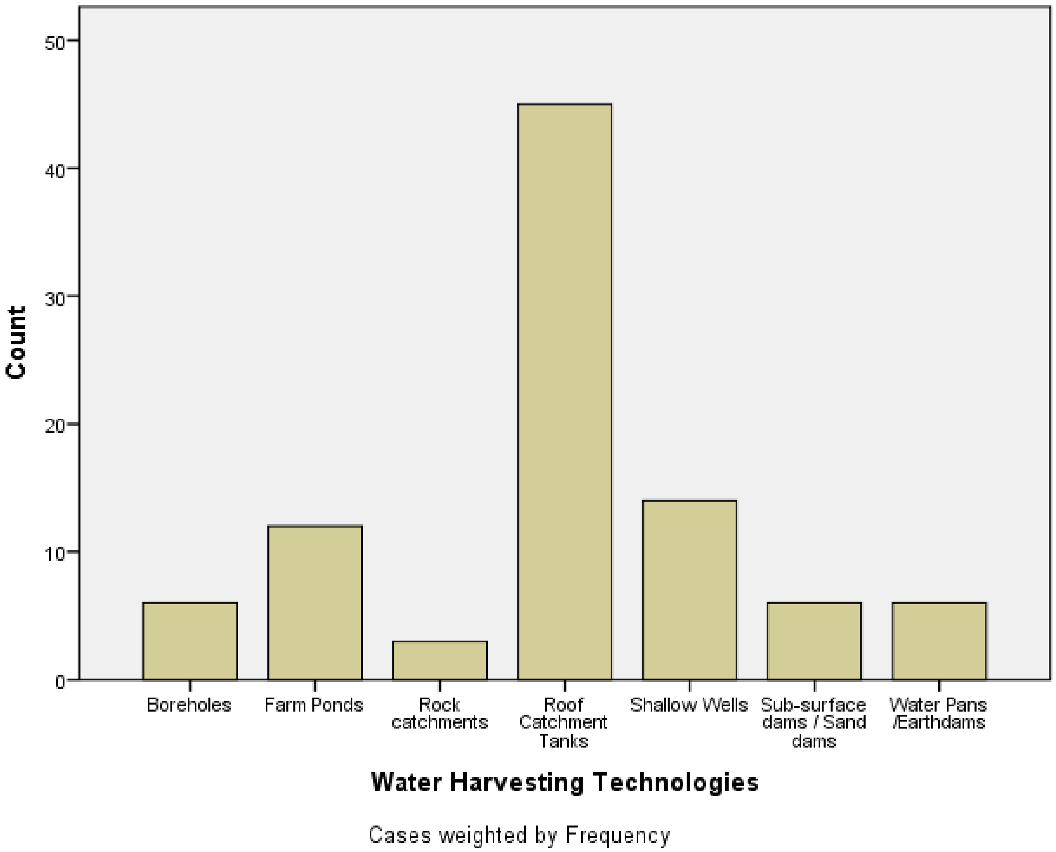


Figure 4.1 : Bar Chart on water harvesting technologies

Table 4.1 and Figure 4.1 show that roof catchment tanks are the most popular (48.9%), followed by shallow wells at (15.2%). The water sources are however not much reliable due to persistent drought in the study area. Some of the water sources dry up immediately after secession of rains, while others last just a few months after end of the rain season. The capacity of the watering points cannot sustain the community water demand for both domestic and agricultural use. The water sources such as earth dams, wells, boreholes and farm ponds lose lots of water to the ground through deep percolation and seepage, while another amount is lost to the atmosphere through evaporation.

4.1.1 Mapping of Major Water Points

Major water points within the study area, were as indicated in figure 4.11 below. This was achieved through use of QGIS technology.

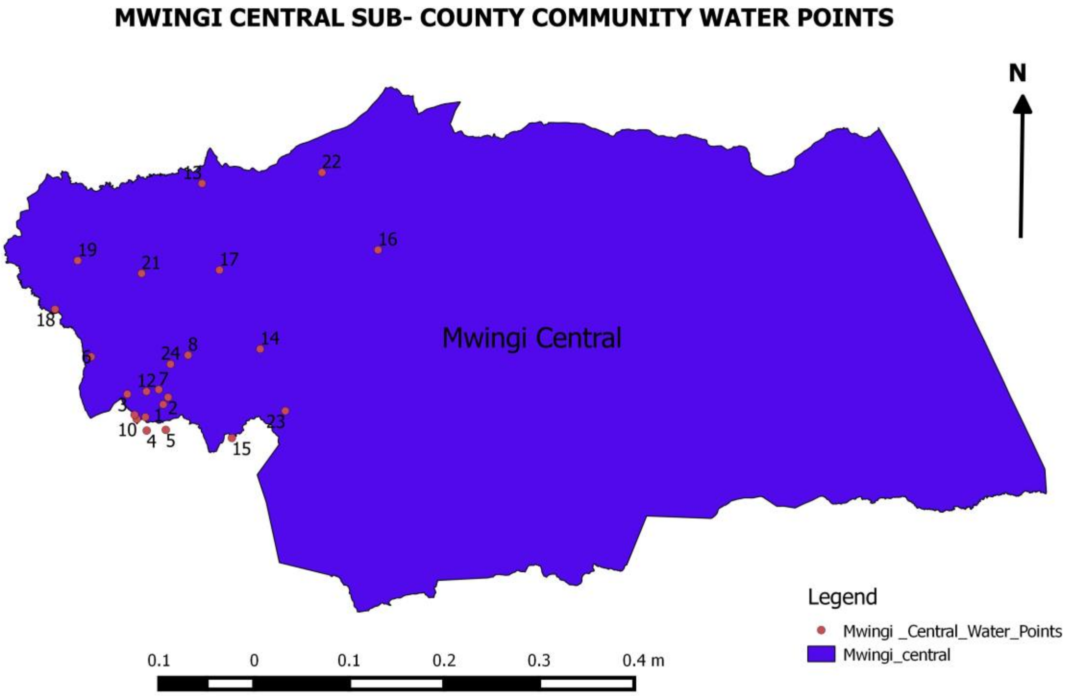


Figure 4.1.1: Map of water points

Table 4.1.1 below captures the respective mapped watering points as per the serial numbers indicated on the map above.

Table 4.1.1: Attribute table on mapping of major watering points

S/No.	Name of Water Points	Latitude	Longitude
1.	Kavuvwani Borehole	-0.98446	38.033885
2.	Kwa Kariavu Sand Dam	-0.976883	38.0389
3.	Mutalia Borehole	-0.973567	37.996038
4.	KIIA Rock Catchment	-1.011978	38.016437
5.	Misai Borehole	-1.011218	38.036532
6.	Kiio Rock Catchment	-0.934322	37.958005
7.	Mathungi Borehole	-0.968843	38.029125
8.	Mwingi Water Supply Kiosk	-0.932502	38.060013
9.	Mumbuni Earth Dam	-0.997717	38.015073
10.	Tivui Rock Catchment	-0.9998555	38.006003
11.	Kasovi Earth Dam	-0.995363	38.003672
12.	Mathungi Sand Dam	-0.970757	38.016193
13.	Kisole Earth Dam	-0.751694	38.074637
14.	Kivou Shallow Well	-0.926093	38.135884
15.	Katalwa Shallow Well	-1.019742	38.106071
16.	Kiiya Earth Dam	-0.821688	38.259942
17.	Yambyu Rock Catchment	-0.842854	38.093023
18.	Ndiuni Sub- Surface Dam	-0.884041	37.919987
19.	Karura Sub- Surface Dam	-0.832904	37.943784
20.	Kianziani Earth Dam	-0.884118	37.919998
21.	Kavauni Borehole	-0.846438	38.011012
22.	Kamunyu Borehole	-0.740123	38.200962
23.	Kanzui Borehole	-0.991214	38.162382
24.	Tyaa Kanginga Oasis Borehole	-0.942008	38.041438

More information on inventory of the water sources in Mwingi Central Sub-County is appended in appendix D and F.

4.1.2 Key Stakeholders in Implementation of Water Harvesting Structures

The main stakeholders in implementation of water harvesting structures in the study area as given by key informants were; Church world service, WASH – Salvation Army sponsored primary schools, Kitui County Government, National Government, ADRA Kenya/Japan- Ministry of Foreign affairs Japan, NDMA- National Drought Management Authority, Caritas Kitui, SNV, WVK, NGAAF – National Government Affirmative Action Fund.

4.1.3 Key Challenges of Existing Watering Points

The main challenges faced by the respondents on community watering points are mainly; long distances to the watering points 31.3%, contaminated and polluted water resources 29.3%, drying of the water resources during drought periods 14% and poor rural access roads 12% among others. This is illustrated in table 4.1.3 and figure 4.1.3 below.

Table 4.1.3: Community watering points challenges

Challenges	Frequency	Percent	Cumulative Percent
Saline water	9	6.0	6.0
poor rural access roads	18	12.0	18.0
siltation / polluted water sources	44	29.3	47.3
Long distances to watering points	47	31.3	78.7
insecure watering points	11	7.3	86.0
Drying of water sources	21	14.0	100.0
Total	150	100.0	

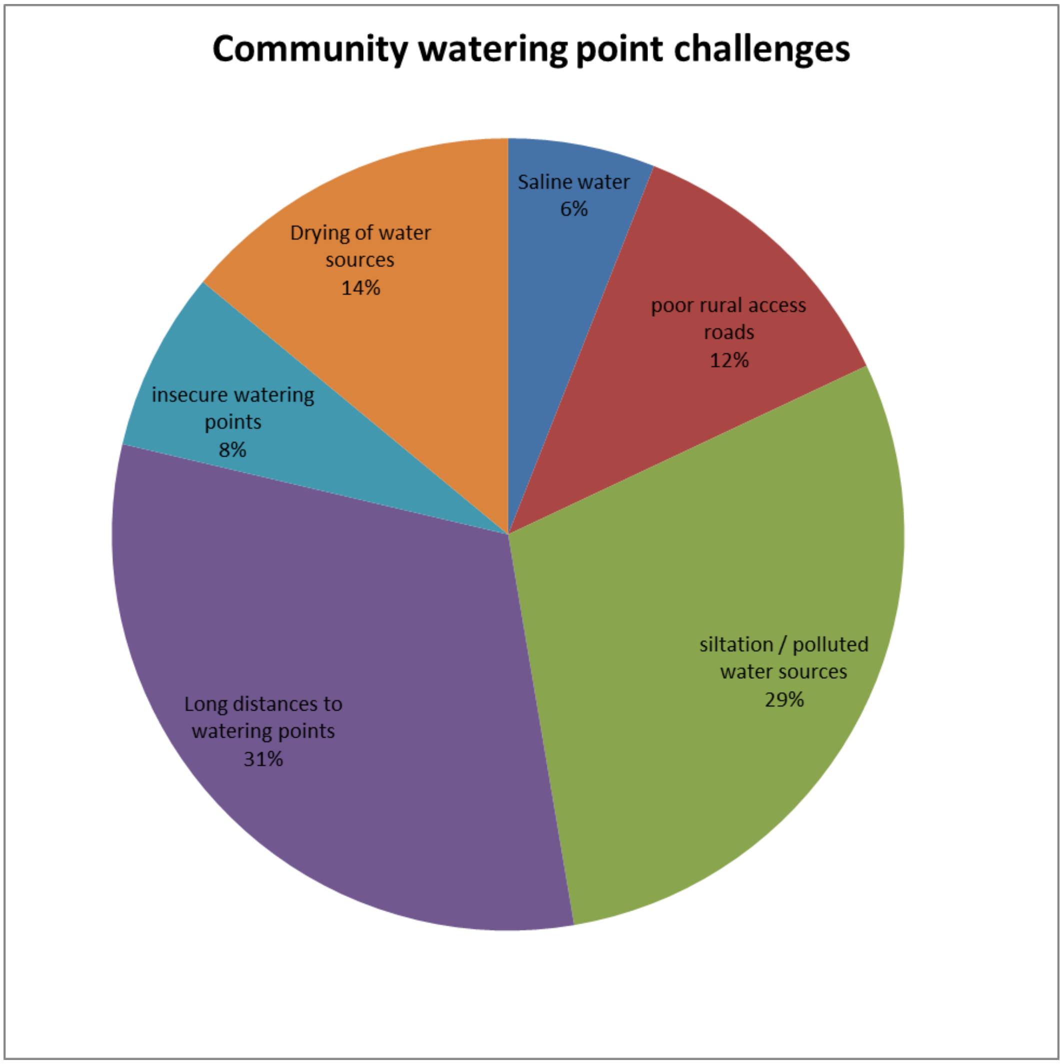


Figure 4.1.3: Challenges on community watering points

The main challenges facing the existing watering points are; high siltation rates of earthen dams and water pans, low water table levels in shallow wells, life risking watering points e.g. very deep sand river wells, human settlement and activities within the catchment areas leading to pollution of the watering points, bore hole water is usually saline and is usually used for watering animals and other domestic uses other than for drinking and cooking, long distances to the watering points, congestion at the watering points, inadequate designs, like lack of silt traps and spill ways and safe water drawing points, lack of fencing of the water harvesting systems, un-functional community water management committees, and drying of watering points during drought periods.

4.1.4 The Practiced Rainwater Harvesting Technologies at Household Level

Table 4.1.4 and figure 4.1.4 below represents the various practiced rainwater harvesting technologies at household level. The roof water harvesting technology was the most popular in the study area representing 62.7 percent, and 29.3 percent of the respondents had not adopted any of the rainwater harvesting techniques.

Table 4.1.4: Rainwater harvesting technologies at household level

RWH technologies at household level	Frequency	Percent	Cumulative Percent
Roof	94	62.7	62.7
Farm pond	2	1.3	64.0
Roof + Shallow well	5	3.3	67.3
Roof+pond	3	2.0	69.3
None	44	29.3	98.7
Farm pond + well	1	.7	99.3
Roof + Farm Pond + Well	1	.7	100.0
Total	150	100.0	

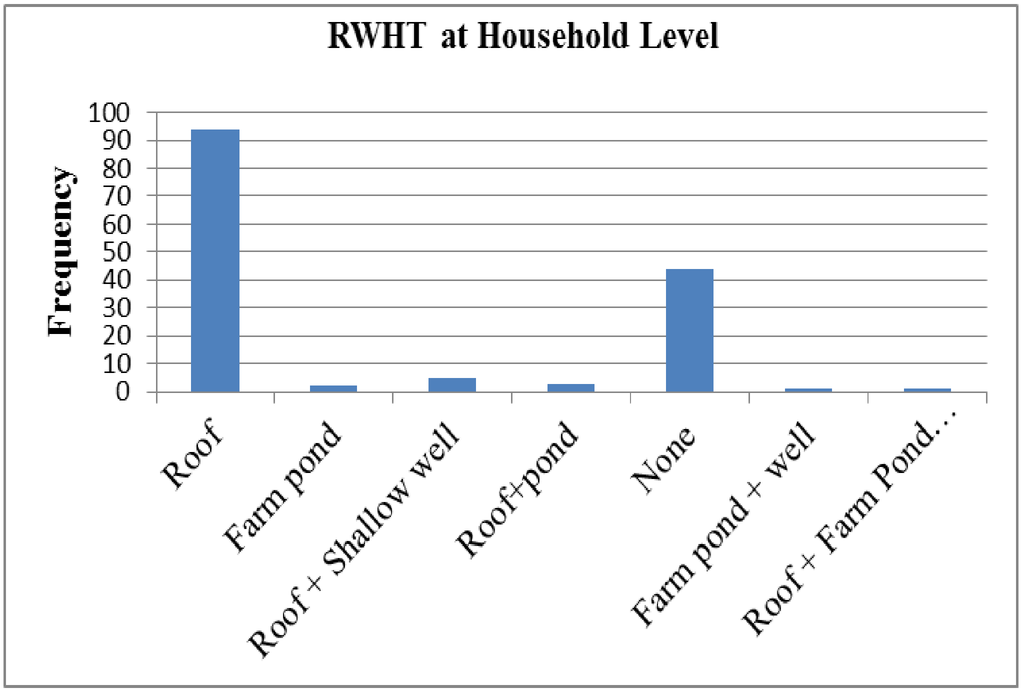


Figure 4.1.4: Rainwater harvesting technologies at household level

Rooftop RWH systems are the most popular due to their high perceived reliability levels.

4.1.5 Main Causes of Low Adoption of Rainwater Harvesting Technologies at Household Level

The respondents cited low income at 42.7%, followed by limited knowledge and skills on rainwater harvesting at 30.7% as the major causes of low adoption of rainwater harvesting technologies among others. This is illustrated in table 4.1.5 and figure 4.1.5 below.

Table 4.1.5: Causes of low adoption of rainwater harvesting technologies

Causes of low adoption of RWH technologies	Frequency	Percent	Cumulative Percent
Low income	64	42.7	42.7
High cost of storage tanks	13	8.7	51.3
Limited Knowledge and Skills on RWH	46	30.7	82.0
Un predictable rainfall patterns	10	6.7	88.7
Water losses from storage facilities	17	11.3	100.0
Total	150	100.0	

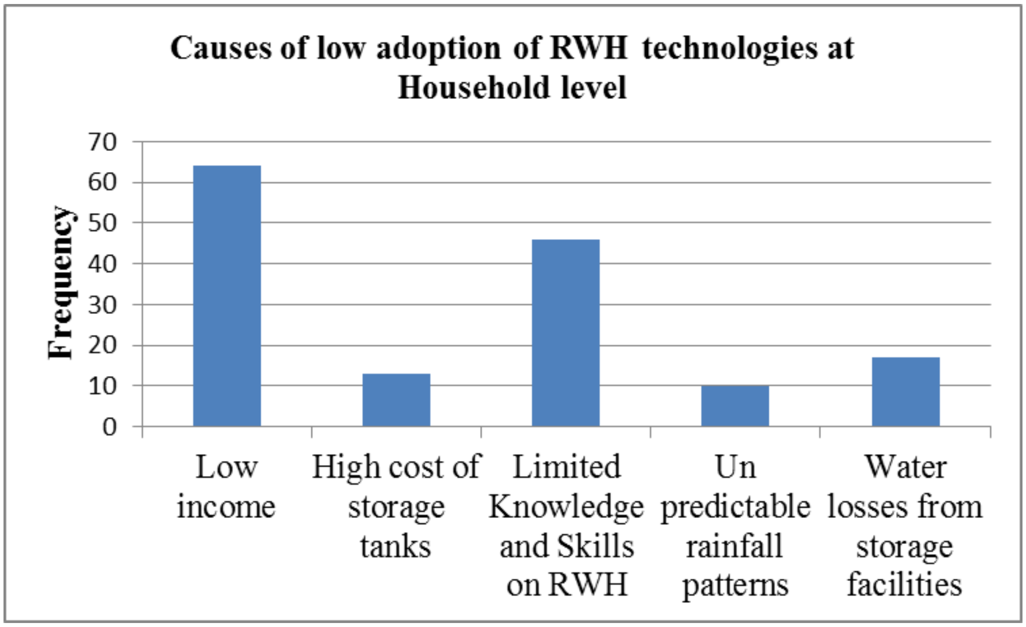


Figure 4.1.5: Causes of low adoption of rainwater harvesting technologies

The greatest hindrance to water harvesting in the study area is poverty leading to low household income levels that leads to lack of funds for purchasing the necessary facilities. Installation of sufficient and reliable rainwater harvesting techniques is expensive and not affordable to many residents. However, the few who have invested intensively in rainwater harvesting have experienced its beneficial effects. They no longer fetch water from the challenging community watering points, have saved a lot of time and energy which is used for other productive purposes. Some also use the water to irrigate their kitchen gardens with a few engaging in commercial vegetable and fruits farming. Those who harvest surplus amount of water sell it locally to the nearby residents during the dry season.

4.1.6 Rating of Household Level of Water Availability

From Table 4.1.6 and figure 4.16 below it can be concluded that majority of the respondents representing 78% had scarce water levels at household level with only 6 % considered as having adequate water levels. This is an indicator of the high levels of household water insecurity in the study area.

Table 4.1.6: Frequency table on level of household water availability

Level of household water availability	Frequency	Percent	Cumulative Percent
Scarce	117	78.0	78.0
Moderate	23	15.3	93.3
Adequate	9	6.0	99.3
Very Adequate	1	0.7	100.0
Total	150	100.0	

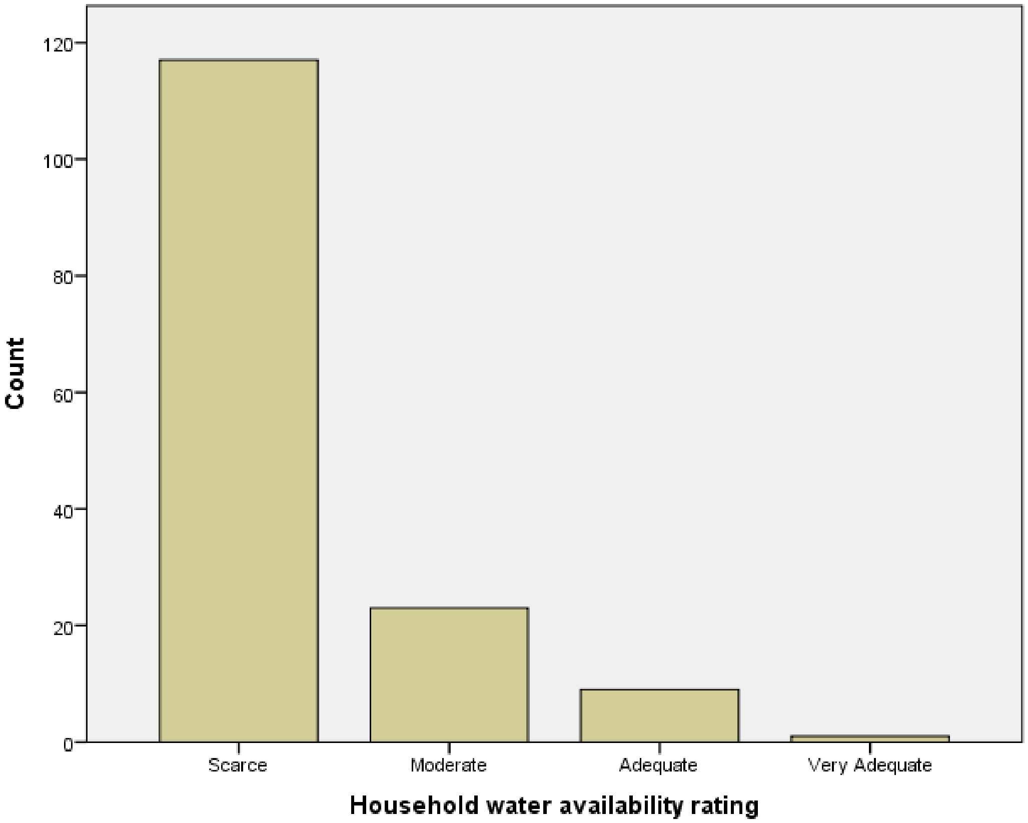


Figure 4.1.6: Graph representing levels of household water availability

4.1.7 Type of Storage Tanks

The main types of storage tanks used for rainwater harvesting in the study area were plastic tanks representing 62 percent, followed by concrete/reinforced concrete at 7.3 percent. Table 4.1.7 and figure 4.1.7 below illustrates the various types of tanks used by the respondents in the study area.

Table 4.1.7: Type of storage tanks

Type of storage tanks	Frequency	Percent	Cumulative Percent
concrete / reinforced concrete	11	7.3	7.3
Plastic	93	62.0	69.3
Bricks (Masonry)	9	6.0	75.3
None	36	24.0	99.3
Metallic	1	0.7	100.0
Total	150	100.0	

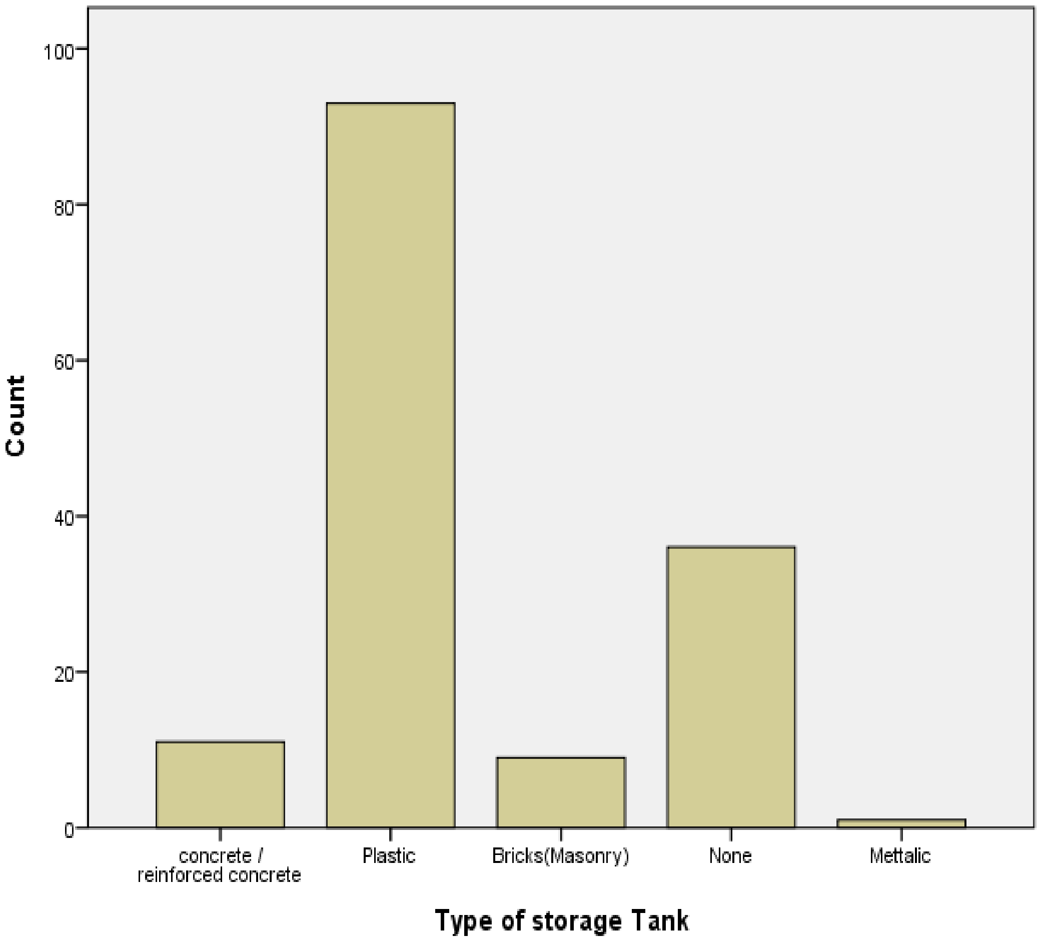


Figure 4.1.7: Graph representing types of storage tanks

The plastic containers used at household level are not much prone to losing water stored in them; hence they are more reliable and popular in storing water for a long time. Concrete and brick wall tanks are prone to cracking and leaking, leading to their low levels of reliability, and declining popularity.

4.2 Performance Evaluation of Rooftop and Farm Pond Water Harvesting Systems

4.2.1 Family Size Analysis

Table 4.2.1: Family size analysis

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Family Size	150	2	14	6.63	2.209
Valid N (listwise)	150				

Table 4.2.1, above is an analysis of the family size within the study area, it is observed that the average family size in the study area is approximately seven (7) members.

Table 4.2.1.2: Family size frequency analysis

Family Size	Frequency	Percent	Cumulative Percent
2	2	1.3	1.3
3	4	2.7	4.0
4	17	11.3	15.3
5	24	16.0	31.3
6	34	22.7	54.0
7	26	17.3	71.3
8	17	11.3	82.7
9	7	4.7	87.3
10	11	7.3	94.7
11	2	1.3	96.0
12	5	3.3	99.3
14	1	.7	100.0
Total	150	100.0	

The above table 4.2.1.2 is a frequency analysis of the family size, and it is observed that most families have six (6) members at 22.7 %, followed by seven (7) members at 17.3%. This is graphically represented in the Figure 4.2.1 and Figure 4.2.1.1 below.

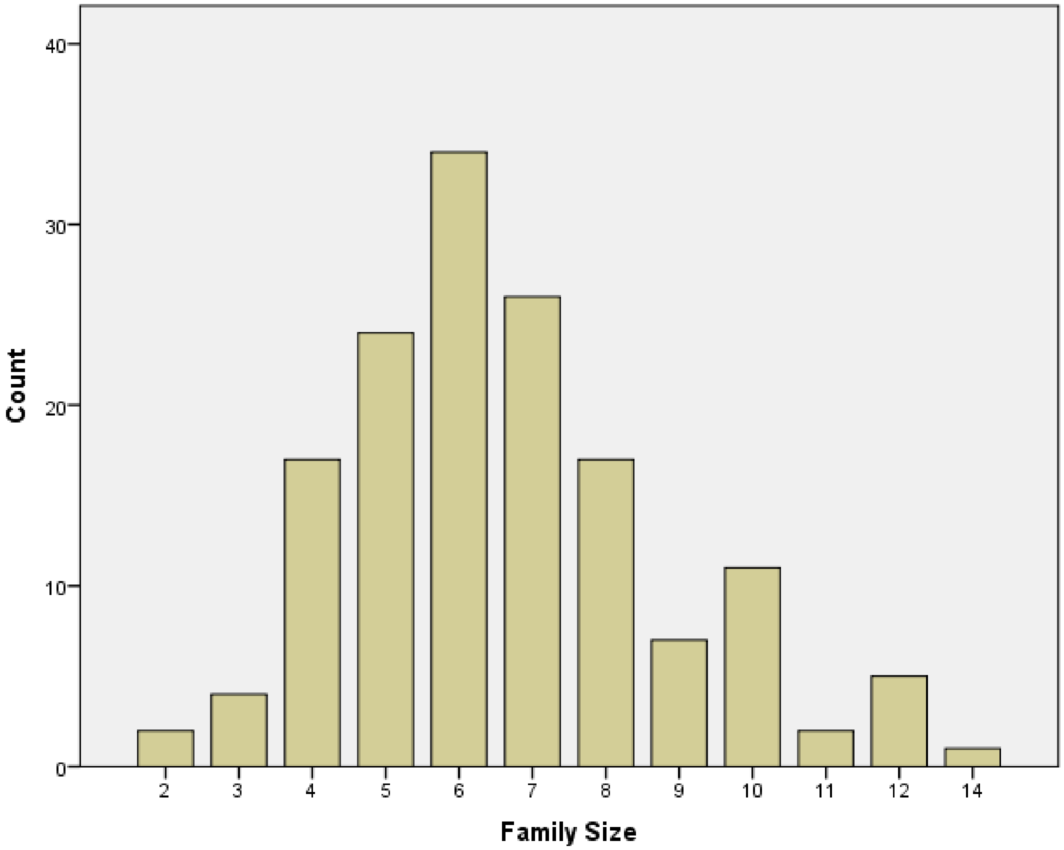


Figure 4.2.1 : Bar Chart on family size analysis

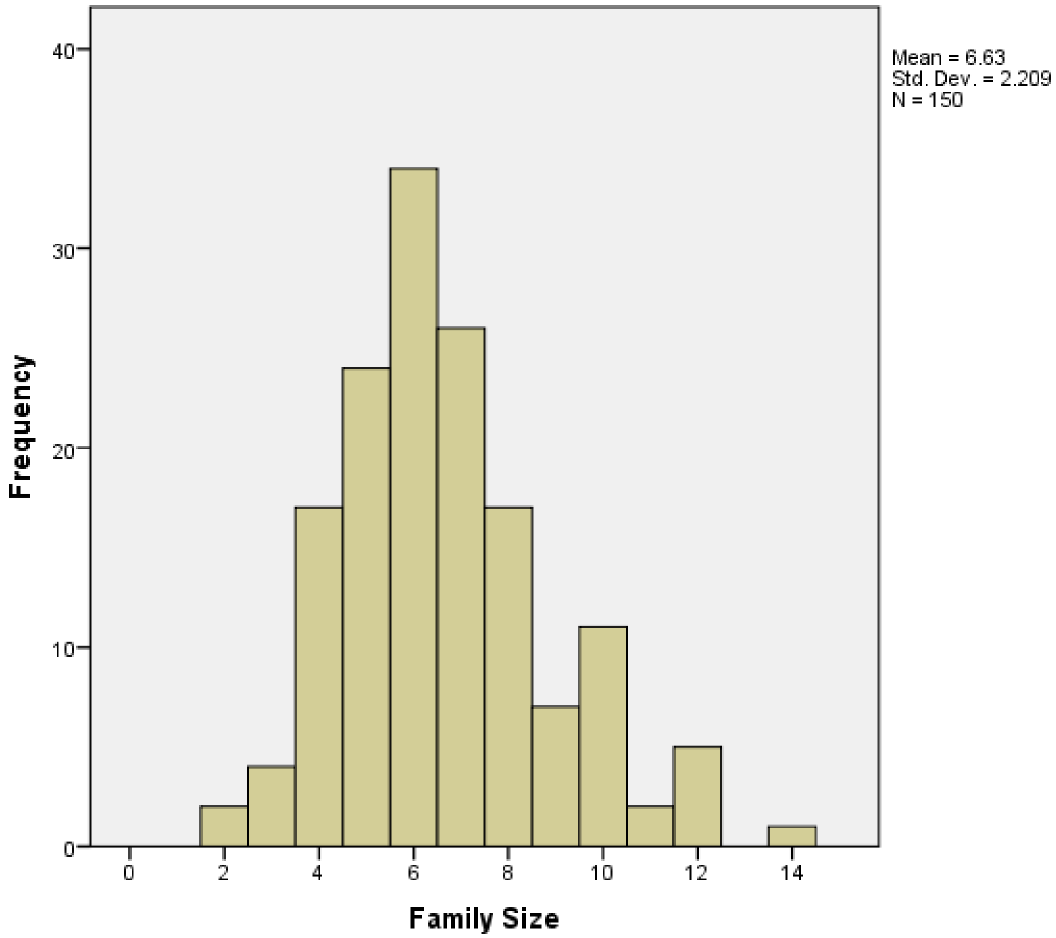


Figure 4.2.1.1: Histogram on family size analysis

4.2.2 Precipitation Analysis

To determine the area rainfall unpredictability, statistical analysis was performed on acquired thirty-year rainfall data. Parameters determined were, standard deviation, mean yearly and mean monthly precipitation and over-all variability over yearly and monthly period. Table 4.2.2 below is a record of the summarized annual rainfall as received from Mwingi central meteorological station, while table 4.2.2.1 is a calculation of the standard deviation.

Table 4.2.2: Annual rainfall data

year	Rainfall mm
1984	700.7
1985	593.4
1986	593.6
1987	417.8
1988	600.6
1989	927.5
1990	1205.4
1991	598.2
1992	572.8
1993	965.8
1994	364.3
1995	Data Missing
1996	Data Missing
1997	Data Missing
1998	Data Missing
1999	Data Missing
2000	Data Missing
2001	505.4
2002	666.4
2003	Data Missing
2004	650.4
2005	301.8
2006	922.6
2007	449.1
2008	378.5
2009	472.4
2010	603.5
2011	719.5
2012	630.5
2013	335.6
2014	495.2
2015	679.6
2016	502.7
2017	399.6

Table 4.2.2.1: Calculation of standard deviation

A = Rainfall mm	B = Mean Rainfall	A-B =C	C^2
700.7	602	98.7	9741.69
593.4	602	-8.6	73.96
593.6	602	-8.4	70.56
417.8	602	-184.2	33929.64
600.6	602	-1.4	1.96
927.5	602	325.5	105950.3
1205.4	602	603.4	364091.6
598.2	602	-3.8	14.44
572.8	602	-29.2	852.64
965.8	602	363.8	132350.4
364.3	602	-237.7	56501.29
505.4	602	-96.6	9331.56
666.4	602	64.4	4147.36
650.4	602	48.4	2342.56
301.8	602	-300.2	90120.04
922.6	602	320.6	102784.4
449.1	602	-152.9	23378.41
378.5	602	-223.5	49952.25
472.4	602	-129.6	16796.16
603.5	602	1.5	2.25
719.5	602	117.5	13806.25
630.5	602	28.5	812.25
335.6	602	-266.4	70968.96
495.2	602	-106.8	11406.24
679.6	602	77.6	6021.76
502.7	602	-99.3	9860.49
399.6	602	-202.4	40965.76
			1156275

The variance (σ^2) = 1156275÷ (27-1) = 44472.1154

The standard deviation (σ) = 210.884

Table 4.2.2.2: Descriptive statistics of annual rainfall data

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Rainfall (mm)	27	301.8	1205.4	601.959	210.8841
Valid N (listwise)	27				

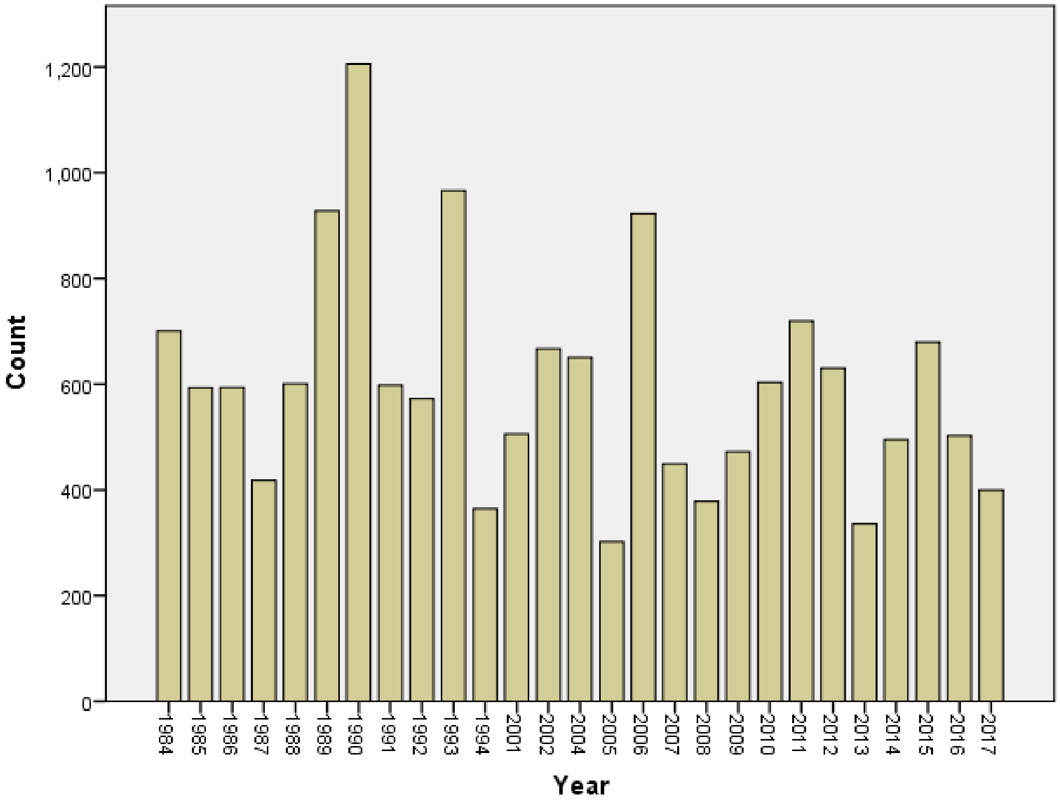
Table 4.2.2.2 gives the descriptive statistics of the rainfall data, with mean rainfall of approximately 602 mm.

Table 4.2.2.3: Rainfall data analysis

S/No.	year	Rainfall mm
1	1984	700.7
2	1985	593.4
3	1986	593.6
4	1987	417.8
5	1988	600.6
6	1989	927.5
7	1990	1205.4
8	1991	598.2
9	1992	572.8
10	1993	965.8
11	1994	364.3
12	2001	505.4
13	2002	666.4
14	2004	650.4
15	2005	301.8
16	2006	922.6
17	2007	449.1
18	2008	378.5

19	2009	472.4
20	2010	603.5
21	2011	719.5
22	2012	630.5
23	2013	335.6
24	2014	495.2
25	2015	679.6
26	2016	502.7
27	2017	399.6

Data on table 4.2.2.3 above is used to develop annual rainfall variability graphs represented in figures 4.2.2, 4.2.2.1, and 4.2.2.2.



Cases weighted by Rainfall (mm)

Figure 4.2.2: Annual rainfall variability bar graph

From figure 4.2.2 the year 1990 recorded the highest amount of annual precipitation.

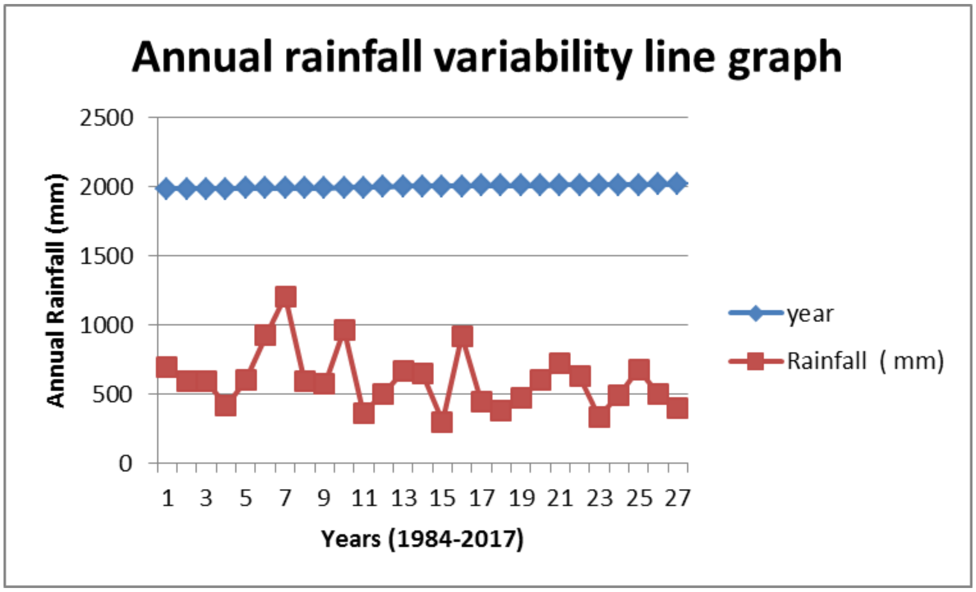


Figure 4.2.2.1: Annual rainfall variability line graph

Figure 4.2.2.1 above shows significant annual rainfall variability over the study period.This is a justification of the unpredictable nature of rainfall pattern in the study area over time.

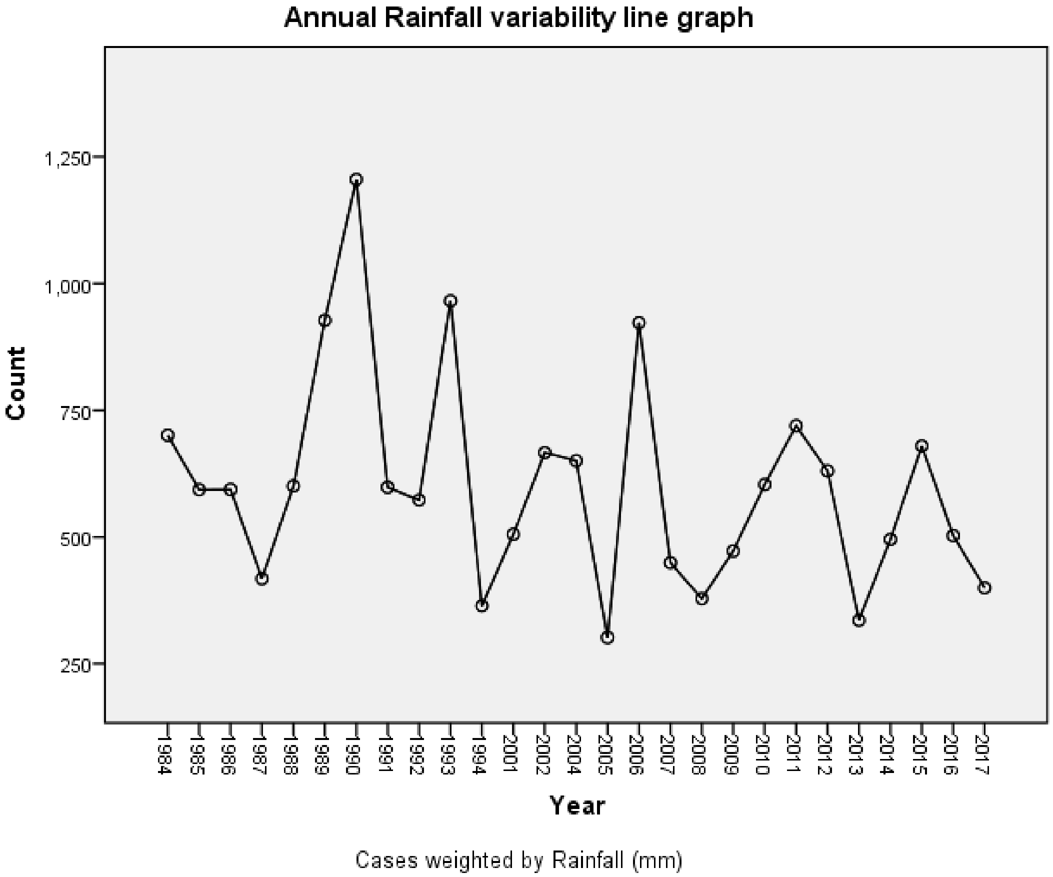


Figure 4.2.2.2: Annual rainfall variability line graph (11)

Figure 4.2.2.2 above shows a significant annual rainfall variability over the period under consideration, with a few years receiving over 900mm and many others receiving below 500mm.

Table 4.2.2.4: Monthly rainfall variability

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
January	24	.00	262.90	69.4417	80.96366
February	25	.00	72.50	18.2440	24.88703
March	25	.00	72.50	15.8720	22.36753
April	25	5.20	307.20	99.0168	72.62282
May	25	.00	311.90	50.6280	77.53172
June	25	.00	42.10	5.7680	10.85586
July	25	.00	6.40	.3920	1.39610
August	24	.00	19.50	1.6125	4.41335
September	23	.00	24.40	1.6087	5.28333
October	24	.00	195.70	30.2375	50.35636
November	24	.00	548.80	170.1000	140.30552
December	24	.00	440.00	144.3833	128.55248
Valid N (listwise)	23				

Table 4.2.2.4 above is a descriptive statistics of monthly rainfall data in appendix B.It gives the mean monthly rainfall data and their respective standard deviation over 30 years period. This again shows significant variability as illustrated in figures 4.2.2.3 and 4.2.2.4 below.

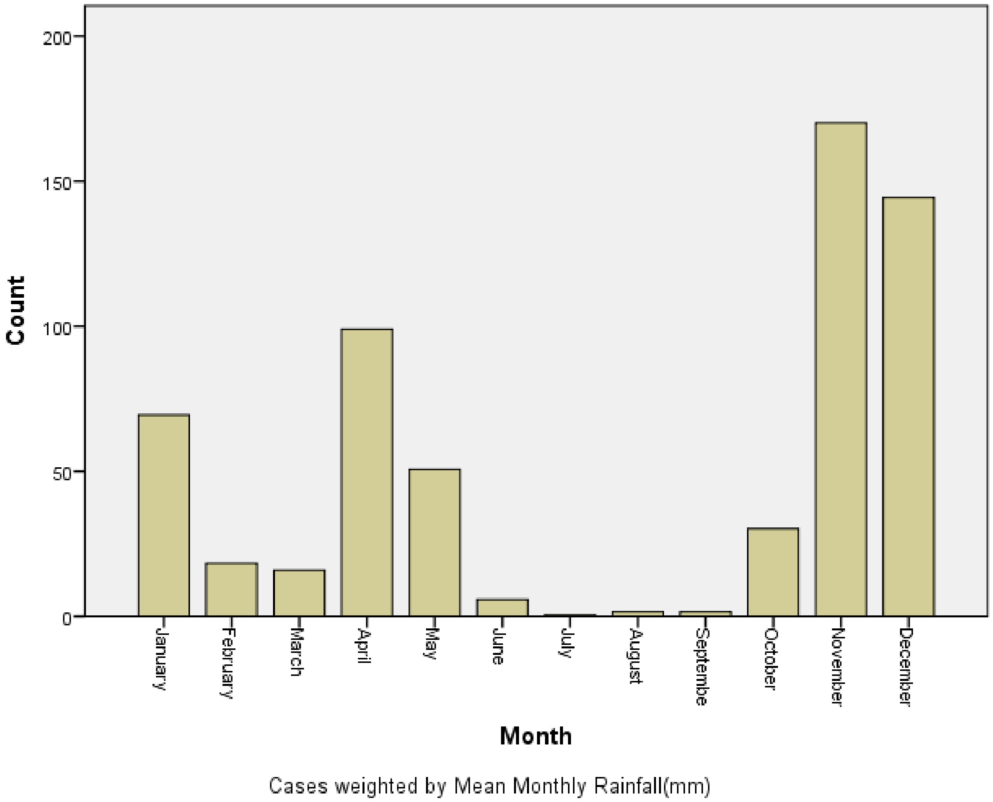


Figure 4.2.2.3: Mean Monthly Rainfall variability bar graph

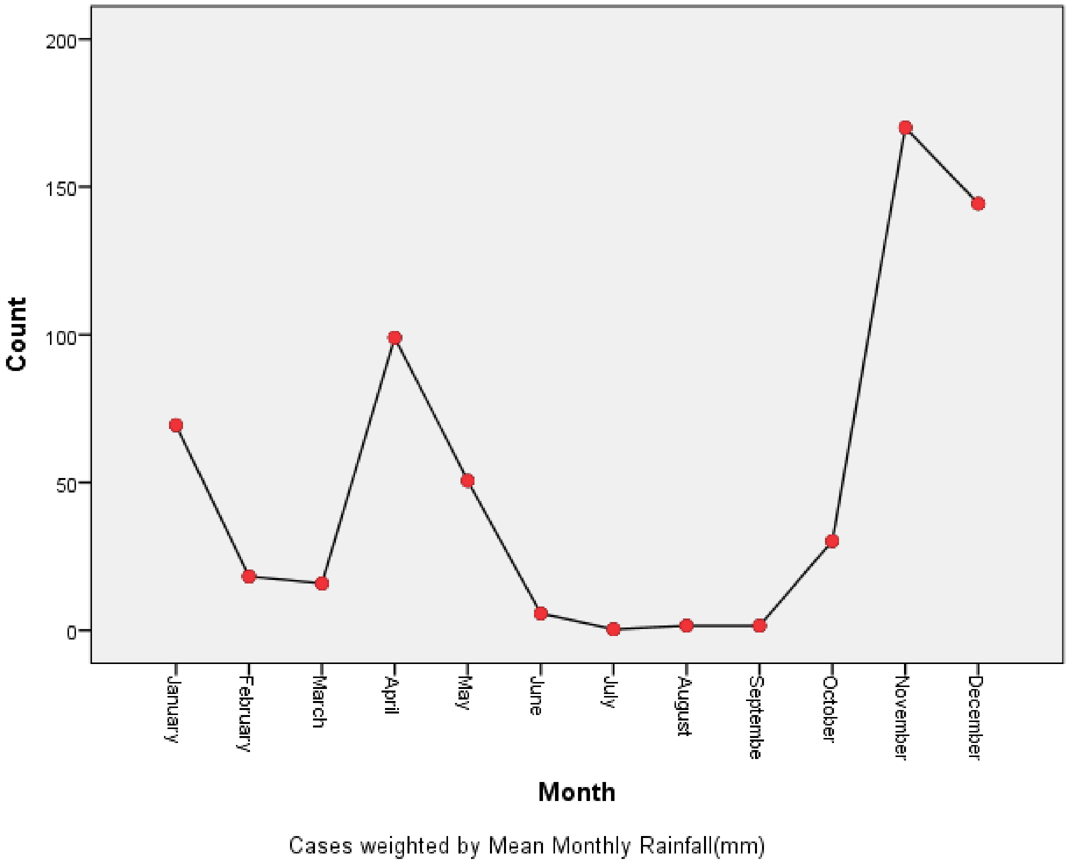


Figure 4.2.2.4: Mean monthly rainfall variability line graph

The figures above illustrate significant rains in the months of October, November, December and January, then April and May. Most dry months are February, March, June, July, August and September, with high rainfall levels over the months of April, November and December.

4.2.3 Household Domestic water Demand and current storage Levels

Roof water harvesting systems were selected for technical evaluation due to their high levels of popularity in the study area.

Roof runoff was calculated by using the below mathematical model:

$Q = P.\,A\,.C$

Where Q = roof runoff into the tank in cubic meters per day,

P = precipitation in meters per day,

A = roof area in square meters and

C = roof runoff coefficient.

Design consideration sourced from FAO irrigation and drainage paper no. 64 manual on small earth dams sets, Domestic water uses to 20-50 litres / day per person. I used 25litres/day per person for design evaluation purpose which is within the recommended range and a roof runoff coefficient of 0.85.

The average precipitation of the study area is taken as 602mm per year. The average number of dry months in the study area is taken as eight (8) months. Running data using the above Roof model reveals that household water requirement could not be fully met from the available rainwater tank capacities, under the above given monthly rainfall time series and that there is generally a mismatch between catchment area and the existing storage capacities. It is therefore recommended that the community members need to increase the capacity (volumes) of Roof water harvesting storage at household level, 98.7 percent of the households had inadequate rainwater harvesting storage capacities. Only 29.3 percent of the households had designed water harvesting systems. While 24 percent of the households had well guttered roof catchments. The mean household roof catchment Area in the study area is approximately 149 $m^{2.}$ with mean annual household rainwater storage levels of $11.72m^3$.

Table 4.2.3: Frequency table on storage capacity levels

	Frequency	Percent	Cumulative Percent
Adequate	2	1.3	1.3
Inadequate	148	98.7	100.0
Total	150	100.0	

Table 4.2.3, above shows most households as having inadequate storage capacities.

Table 4.2.3.1: Design of water harvesting systems

	Frequency	Percent	Cumulative Percent
yes	44	29.3	29.3
No	106	70.7	100.0
Total	150	100.0	

Table: 4.2.3.1, above shows only 29.3 household roof top water harvesting systems being technically designed.

Table 4.2.3.2: Guttering of Rooftop Catchments

	Frequency	Percent	Cumulative Percent
yes	36	24.0	24.0
no	114	76.0	100.0
Total	150	100.0	

From table 4.2.3.2 only 24 percent of the roof catchments were adequately guttered.

Table 4.2.3.3: Household roof catchment area

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Roof Area (m^2)	150	12	800	148.83	129.319
Valid N (listwise)	150				

From table 4.2.3.3 above, the mean household roof catchment area was 149m^2, but ranging from as low as 12 m^2 to 800 m^2.

Table 4.2.3.4: Annual household rainwater storage levels

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Annual Rainwater Storage levels in cubic metres)	150	.00	365.00	17.7151	46.76130
Valid N (listwise)	150				

The mean annual household rainwater storage capacities were 17.72 m³, but significantly varying as illustrated in table 4.2.3.4 above

Table 4.2.3.5: Estimates of annual roof runoff

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Estimates of Annual Roof runoff in cubic metres.	150	6.1404	409.3600	76.158017	66.1723952
Valid N (list wise)	150				

From table 4.2.3.5 above the calculated mean annual roof run off is 76 m³ showing high technical feasibility of RWH in the study area.

Table 4.2.3.6: Estimates of annual household water demand

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Household water demand in cubic metres	150	12.00	84.00	39.8000	13.25182
Valid N (list wise)	150				

From table 4.2.3.6, the estimates of the annual household water demand give a mean of 40 m³. Showing the potential mean supply is not yet exploited.

The mean Annual roof runoff in the study area is approximately $76m^3$. The mean household water demand in the study area is approximately $40m^3$.This is approximately three times more than the current mean household water storage levels. This implies that both roof catchment areas and household storage tanks need to be increased to meet the water demand levels.

Table 4.2.3.7: Annual household rainwater storage levels in cubic metres

Storage Levels in m³	Frequency	Percent	Cumulative Percent
.00	47	31.3	31.3
.10	1	.7	32.0
.20	2	1.3	33.3
.40	11	7.3	40.7
.42	1	.7	41.3
.48	1	.7	42.0
.60	1	.7	42.7
.80	1	.7	43.3
.81	1	.7	44.0
.82	1	.7	44.7
.84	1	.7	45.3
.90	2	1.3	46.7
1.00	2	1.3	48.0
1.20	2	1.3	49.3
1.60	1	.7	50.0
2.00	2	1.3	51.3
2.80	1	.7	52.0
3.00	2	1.3	53.3
3.20	1	.7	54.0

	4.60	2	1.3	55.3
	5.00	5	3.3	58.7
	6.00	7	4.7	63.3
	6.40	1	.7	64.0
	7.00	3	2.0	66.0
	10.00	13	8.7	74.7
	12.00	2	1.3	76.0
	16.00	1	.7	76.7
	18.00	1	.7	77.3
	20.00	9	6.0	83.3
	21.20	1	.7	84.0
	26.00	1	.7	84.7
	30.00	2	1.3	86.0
	40.00	6	4.0	90.0
	50.00	4	2.7	92.7
	52.00	1	.7	93.3
	60.00	1	.7	94.0
	64.00	2	1.3	95.3
	90.00	1	.7	96.0
	100.00	1	.7	96.7
	150.00	1	.7	97.3
	160.00	1	.7	98.0
	200.00	1	.7	98.7
	300.00	1	.7	99.3
	365.00	1	.7	100.0
	Total	150	100.0	

Table 4.2.3.7 above captures frequency data on respective annual household rooftop systems storage capacities in the interviewed households within the study area.

Table 4.2.3.8: Annual household rainwater demand levels in cubic metres

Current Annual Household rainwater demand levels in m^3	Frequency	Percent	Cumulative Percent
12.0	2	1.3	1.3
18.0	4	2.7	4.0
24.0	17	11.3	15.3
30.0	24	16.0	31.3
36.0	34	22.7	54.0
42.0	26	17.3	71.3
48.0	17	11.3	82.7
54.0	7	4.7	87.3
60.0	11	7.3	94.7
66.0	2	1.3	96.0
72.0	5	3.3	99.3
84.0	1	.7	100.0
Total	150	100.0	

Table 4.2.3.8 above captures frequency data on respective annual household domestic water demand capacities in the interviewed households within the study area, with most households having a demand level of 36 m^3, representing 22.7%, followed by 42 m^3 at 17.3%. Figures 4.2.3, 4.2.3.1, 4.2.3.2, and 4.2.3.3 below is a graphical representation of the above scenario of demand and storage levels.

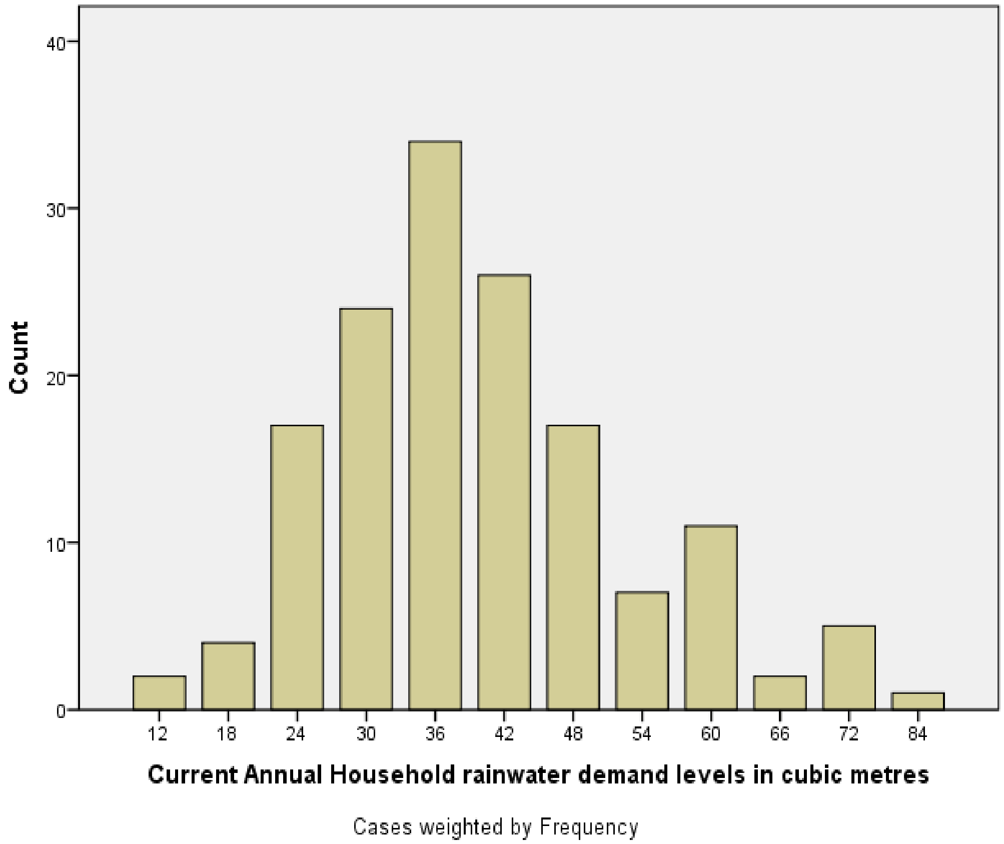


Figure 4.2.3: Annual Household rainwater demand levels in cubic metres

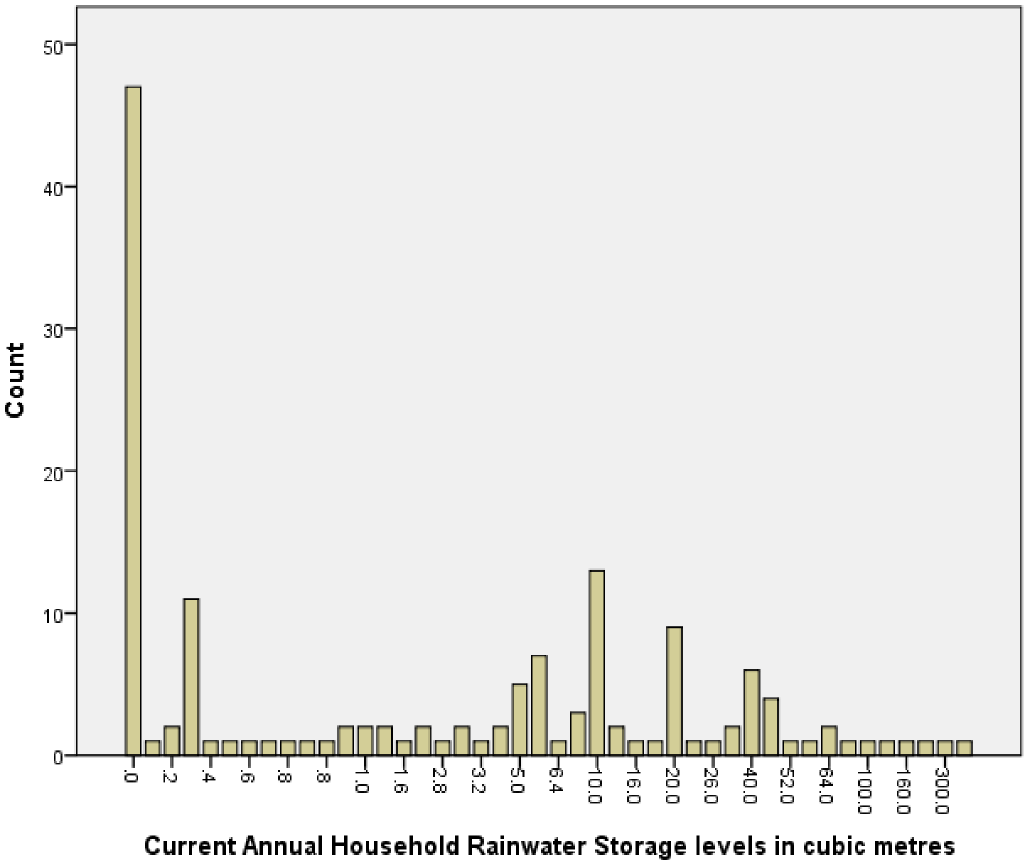


Figure 4.2.3.1: Annual household rainwater storage levels in cubic metres

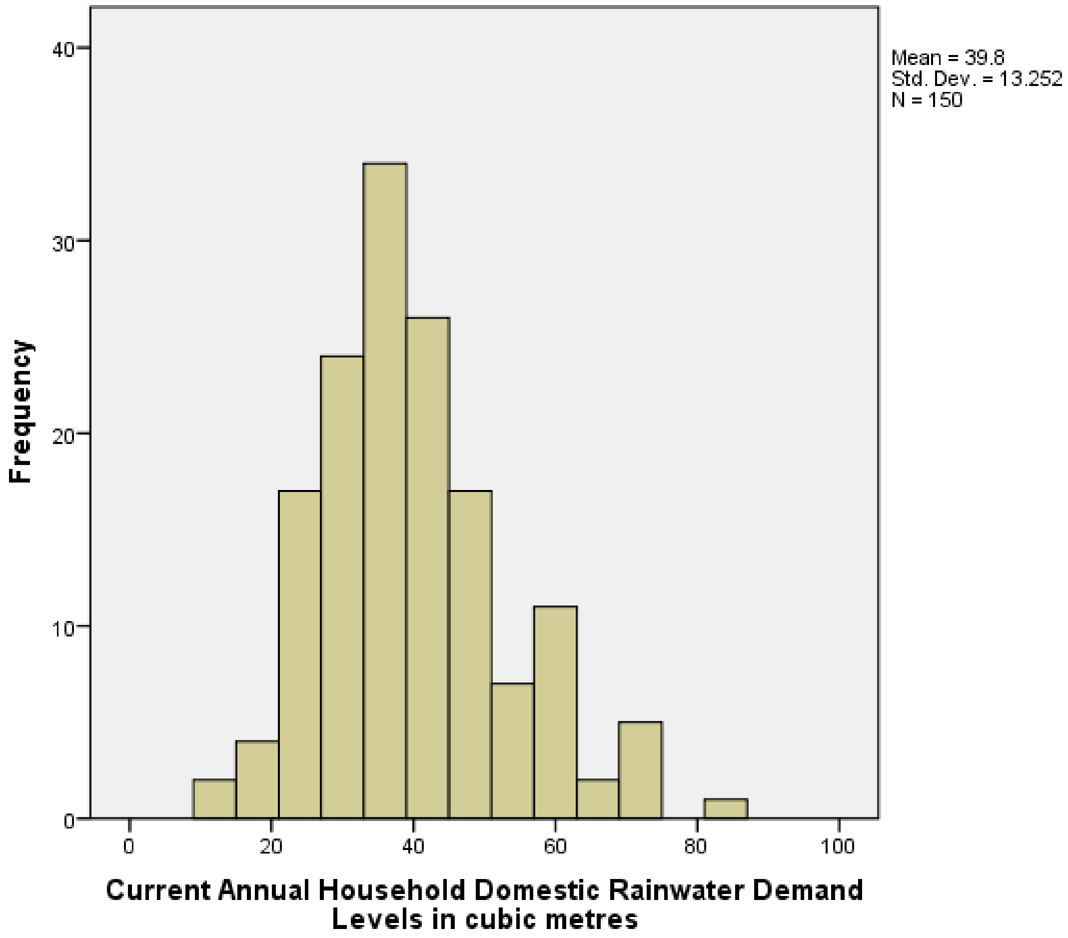


Figure 4.2.3.2: Histogram on annual household water demand levels

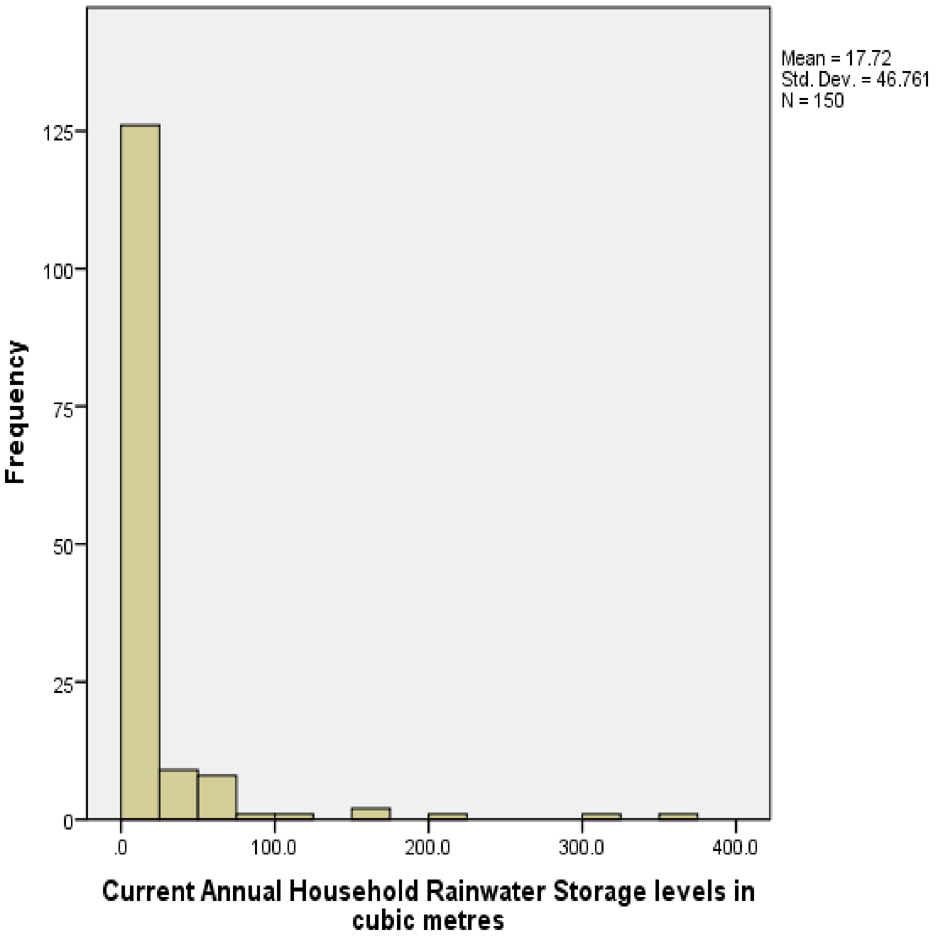


Figure 4.2.3.3: Histogram on annual household water storage levels

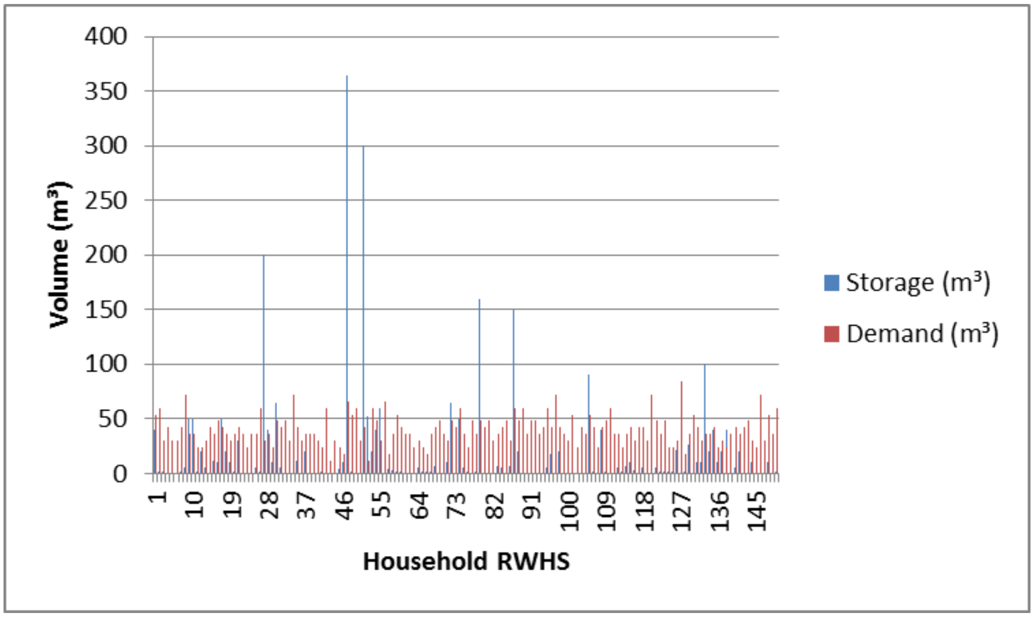


Figure 4.2.3.4: Comparison of annual household water storage capacities to annual household water demand in cubic metres

Figure 4.2.3.4 above illustrates that most of the annual household storage levels are below the calculated annual household water demand levels.

4.2.4 Water Saving Efficiency

Table 4.2.4: Household water saving efficiency

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Water Saving Efficiency	150	.00	714.29	44.8535	107.08202
Valid N (listwise)	150				

From table 4.2.4 the mean household water saving efficiency is 44.85 per cent, this means that majority of the households in the study area are not able to meet their annual household domestic water demand by rooftop water harvesting.

However, a few of the households have surplus water harvested and are therefore able to sale water to their neighbours or engage in small scale irrigated farming for growing of horticultural crops.

Table 4.2.4.1: Household water saving efficiency frequency table

	Frequency	Percent	Cumulative Percent
.00	47	31.3	31.3
.42	1	.7	32.0
.56	1	.7	32.7
.67	1	.7	33.3
.74	1	.7	34.0
.83	3	2.0	36.0
.95	2	1.3	37.3
1.11	1	.7	38.0
1.14	1	.7	38.7
1.17	1	.7	39.3
1.33	1	.7	40.0
1.35	1	.7	40.7
1.67	3	2.0	42.7
2.22	4	2.7	45.3
2.50	1	.7	46.0
3.42	1	.7	46.7
3.50	1	.7	47.3
3.75	1	.7	48.0
4.00	1	.7	48.7
4.17	1	.7	49.3
5.56	1	.7	50.0
6.67	1	.7	50.7
8.33	3	2.0	52.7
8.89	1	.7	53.3
9.33	1	.7	54.0
10.00	2	1.3	55.3

10.42	1	.7	56.0
11.90	1	.7	56.7
13.89	1	.7	57.3
14.29	3	2.0	59.3
16.67	5	3.3	62.7
18.52	1	.7	63.3
19.17	1	.7	64.0
19.44	2	1.3	65.3
20.83	1	.7	66.0
21.33	1	.7	66.7
23.81	2	1.3	68.0
25.56	1	.7	68.7
28.57	1	.7	69.3
33.33	7	4.7	74.0
38.10	1	.7	74.7
41.67	4	2.7	77.3
42.86	1	.7	78.0
47.62	1	.7	78.7
55.56	5	3.3	82.0
66.67	1	.7	82.7
70.67	1	.7	83.3
71.43	1	.7	84.0
72.22	1	.7	84.7
74.07	1	.7	85.3
83.33	4	2.7	88.0
95.24	2	1.3	89.3
111.11	1	.7	90.0
119.05	1	.7	90.7
133.33	2	1.3	92.0
138.89	2	1.3	93.3
166.67	2	1.3	94.7
200.00	1	.7	95.3
250.00	1	.7	96.0

	277.78	1	.7	96.7
	333.33	1	.7	97.3
	433.33	1	.7	98.0
	553.03	1	.7	98.7
	666.67	1	.7	99.3
	714.29	1	.7	100.0
	Total	150	100.0	

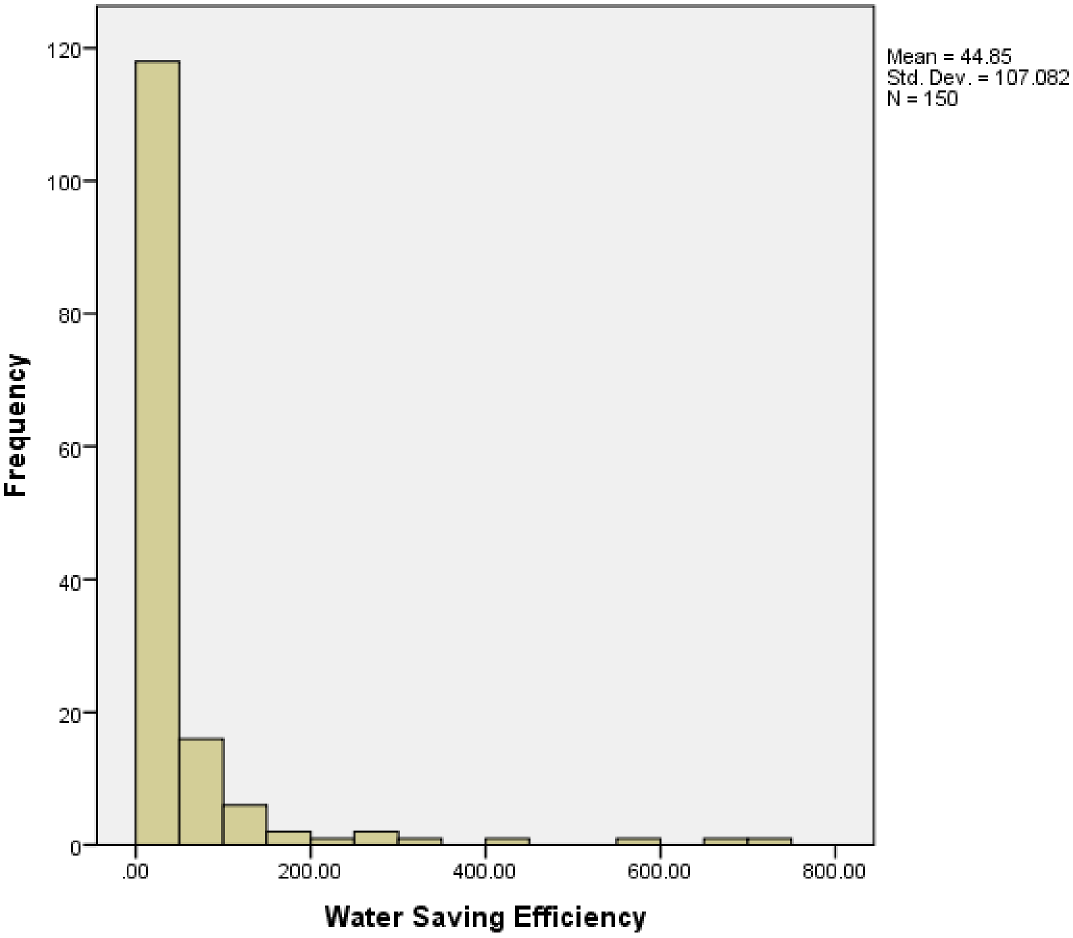


Figure 4.2.4: Histogram on household water saving efficiency

4.2.5 Reliability

Table 4.2.5: Reliability Ratio

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Reliability Ratio	102	.14	240.00	24.7168	43.85860
Valid N (listwise)	102				

Table 4.2.5 shows results of a mean reliability ratio of 24.72, which is much greater than 1.75 as per classes in table 4.2.5.1 below, implying the required water is largely higher than supply, resulting to a very large deficit.

Table 4.2.5.1: Reliability Ratio, Classes and Values

Reliability ratio	Class	Value
Reliability ratio (-), the ratio between the total demand and the total supply of water. High suitability scores for the ratio are close to one	Sufficient (required water is largely less than supply)	< 0.35
	Medium Sufficient	0.35–0.75
	High Sufficient	0.75–1.1
	Large deficit	1.1–1.75
	Very large deficit (required water is largely higher than supply)	>1.75

Source: (Adham, et al., 2016)

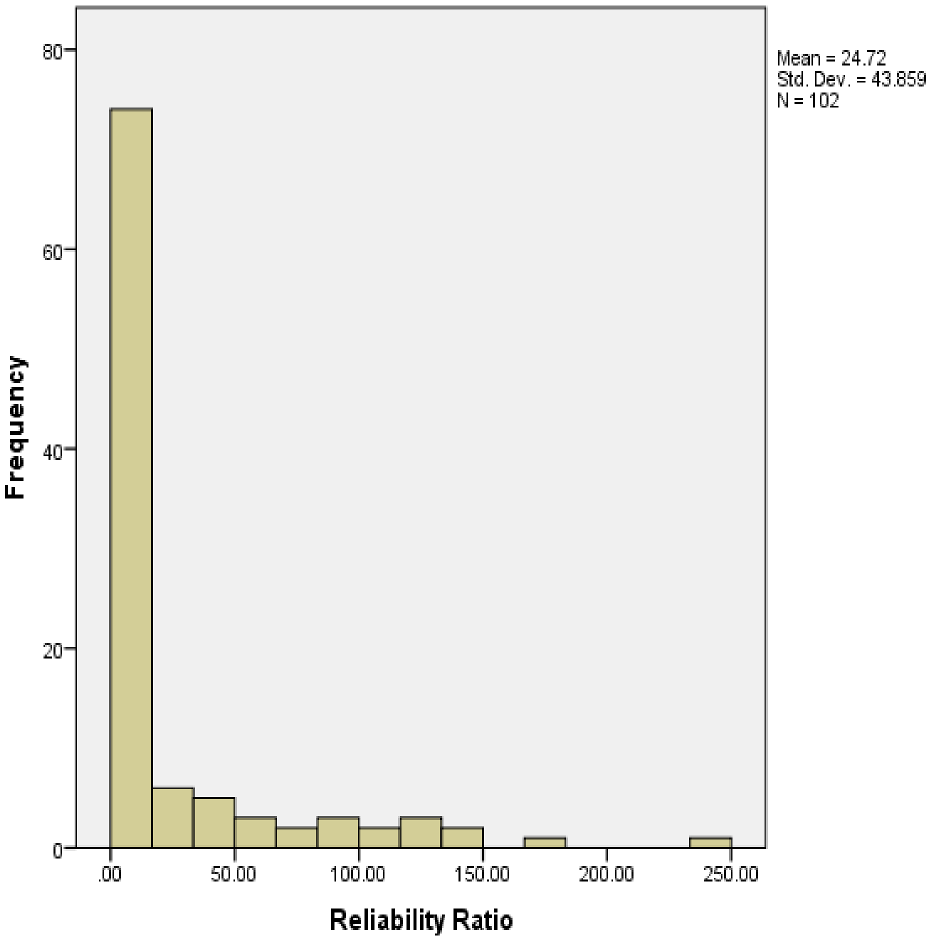


Figure 4.2.5: Reliability Ratio

Table 4.2.5.2: Reliability ratio frequency table

Reliability Ratio	Frequency	Percent	Cumulative Percent
.14	1	1.0	1.0
.15	1	1.0	2.0
.18	1	1.0	2.9
.23	1	1.0	3.9
.30	1	1.0	4.9
.36	1	1.0	5.9
.40	1	1.0	6.9
.50	1	1.0	7.8
.60	2	2.0	9.8

.72	2	2.0	11.8
.75	2	2.0	13.7
.84	1	1.0	14.7
.90	1	1.0	15.7
1.05	2	2.0	17.6
1.20	4	3.9	21.6
1.35	1	1.0	22.5
1.38	1	1.0	23.5
1.40	1	1.0	24.5
1.42	1	1.0	25.5
1.50	1	1.0	26.5
1.80	4	3.9	30.4
2.10	1	1.0	31.4
2.33	1	1.0	32.4
2.40	4	3.9	36.3
2.63	1	1.0	37.3
3.00	7	6.9	44.1
3.50	1	1.0	45.1
3.91	1	1.0	46.1
4.20	2	2.0	48.0
4.69	1	1.0	49.0
4.80	1	1.0	50.0
5.14	2	2.0	52.0
5.22	1	1.0	52.9
5.40	1	1.0	53.9
6.00	5	4.9	58.8
7.00	3	2.9	61.8
7.20	1	1.0	62.7
8.40	1	1.0	63.7
9.60	1	1.0	64.7
10.00	2	2.0	66.7
10.71	1	1.0	67.6
11.25	1	1.0	68.6

12.00	3	2.9	71.6
15.00	1	1.0	72.5
18.00	1	1.0	73.5
24.00	1	1.0	74.5
25.00	1	1.0	75.5
26.67	1	1.0	76.5
28.57	1	1.0	77.5
29.27	1	1.0	78.4
40.00	1	1.0	79.4
45.00	4	3.9	83.3
60.00	3	2.9	86.3
74.07	1	1.0	87.3
75.00	1	1.0	88.2
85.71	1	1.0	89.2
87.50	1	1.0	90.2
90.00	1	1.0	91.2
105.00	2	2.0	93.1
120.00	3	2.9	96.1
135.00	1	1.0	97.1
150.00	1	1.0	98.0
180.00	1	1.0	99.0
240.00	1	1.0	100.0
Total	102	100.0	

Table 4.2.5.3: Reliability Ratio Classes Frequency Table

Reliability Ratio Classes	Frequency	Percent	Cumulative Percent
Sufficient (< 0.35)	5	4.9	4.9
Medium Sufficient (0.35 – 0.75)	7	6.9	11.8
High Sufficient (0.75-1.1)	6	5.9	17.6
Large Deficit(1.1 – 1.75)	8	7.8	25.5
Very Large Deficit (> 1.75)	76	74.5	100.0
Total	102	100.0	

Source: (Adham, et al., 2016)

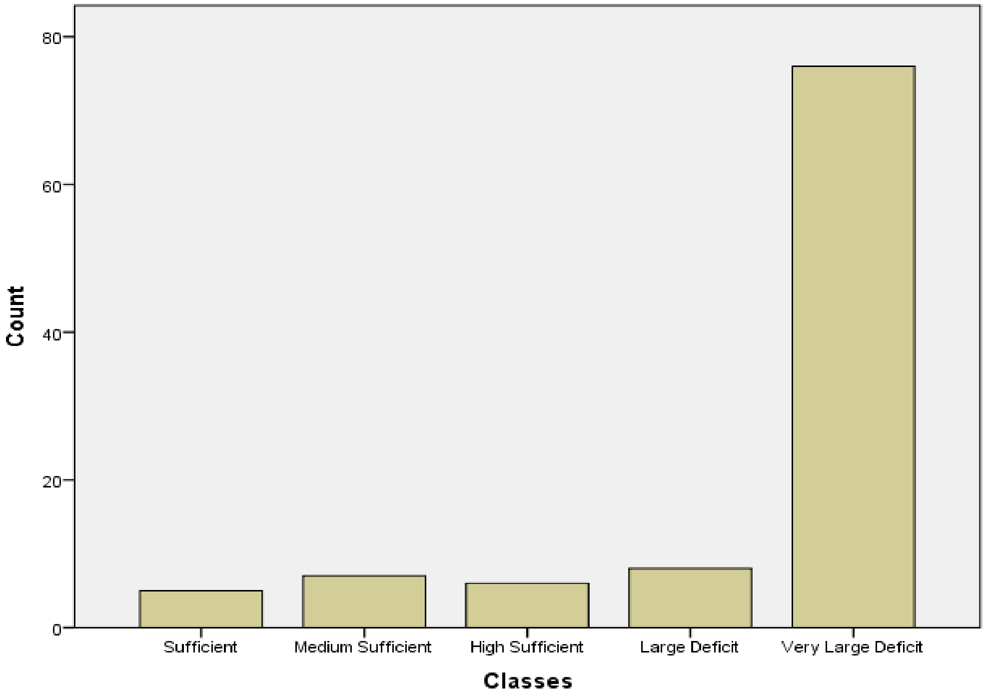


Figure 4.2.5.1: Reliability ratio classes

According to table 4.2.5.3 and figure 4.2.5.1, 74.5 per cent of the households practicing rooftop RWH are classified as having very large deficit. Indicating that required water is largely higher than supply.

4.2.6 Storage Capacity Ratio

Table 4.2.6 : Storage capacity ratio, classes and values

Criteria (Indicator)	**Classes**	**Values**
Storage capacity ratio (-), the ratio between the total volume of water inflow and existing storage capacity. The ratio that is close to one is ranked as highly suitable.	Over requirement (too large a storage capacity area)	<0.5
	Sufficient	0.5–1.0
	Optimum requirement	1.0–2.0
	Critical	2.0–4.0
	Very critical requirement (too small a storage capacity area)	>4.0

Source: (Adham, et al., 2016)

Table 4.2.6.1: Storage capacity ratio

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Storage Capacity Ratio	103	.89	253.29	31.8910	55.90371
Valid N (listwise)	103				

Table 4.2.5.2: Storage capacity ratio frequency table

Storage Capacity Ratio	Frequency	Percent	Cumulative Percent
.89	1	1.0	1.0
.90	1	1.0	1.9
.98	1	1.0	2.9
1.06	1	1.0	3.9
1.12	1	1.0	4.9
1.15	1	1.0	5.8
1.36	1	1.0	6.8
1.60	1	1.0	7.8
1.72	1	1.0	8.7
1.77	1	1.0	9.7
1.96	1	1.0	10.7
2.07	1	1.0	11.7
2.17	1	1.0	12.6
2.81	1	1.0	13.6
2.94	1	1.0	14.6
3.07	1	1.0	15.5
3.09	1	1.0	16.5
3.12	1	1.0	17.5
3.20	1	1.0	18.4
3.33	1	1.0	19.4
3.52	1	1.0	20.4
3.63	1	1.0	21.4
3.89	1	1.0	22.3
3.97	1	1.0	23.3
4.30	1	1.0	24.3
4.61	1	1.0	25.2
4.78	2	1.9	27.2
4.78	1	1.0	28.2
4.80	1	1.0	29.1
4.95	1	1.0	30.1
5.01	1	1.0	31.1
5.12	1	1.0	32.0

	5.20	1	1.0	33.0
	5.54	1	1.0	34.0
	5.73	1	1.0	35.0
	5.97	1	1.0	35.9
	6.06	1	1.0	36.9
	6.27	1	1.0	37.9
	6.36	1	1.0	38.8
	6.45	1	1.0	39.8
	6.91	1	1.0	40.8
	7.40	1	1.0	41.7
	7.42	1	1.0	42.7
	7.50	1	1.0	43.7
	7.68	3	2.9	46.6
	7.93	1	1.0	47.6
	8.04	1	1.0	48.5
	8.14	1	1.0	49.5
	8.19	1	1.0	50.5
	8.29	1	1.0	51.5
	8.57	1	1.0	52.4
	8.70	1	1.0	53.4
	8.95	1	1.0	54.4
	9.06	1	1.0	55.3
	9.72	2	1.9	57.3
	10.23	1	1.0	58.3
	10.49	1	1.0	59.2
	10.75	1	1.0	60.2
	10.85	1	1.0	61.2
	11.05	1	1.0	62.1
	12.54	2	1.9	64.1
	14.33	1	1.0	65.0
	15.35	1	1.0	66.0
	16.37	1	1.0	67.0
	16.54	1	1.0	68.0

17.91	1	1.0	68.9
18.83	1	1.0	69.9
19.96	1	1.0	70.9
21.49	1	1.0	71.8
22.30	1	1.0	72.8
23.03	1	1.0	73.8
23.67	1	1.0	74.8
25.59	1	1.0	75.7
26.22	1	1.0	76.7
29.00	1	1.0	77.7
29.85	1	1.0	78.6
39.80	1	1.0	79.6
40.94	2	1.9	81.6
42.64	1	1.0	82.5
46.05	1	1.0	83.5
49.92	1	1.0	84.5
68.23	1	1.0	85.4
71.64	1	1.0	86.4
79.57	1	1.0	87.4
80.59	1	1.0	88.3
95.94	1	1.0	89.3
115.13	1	1.0	90.3
117.26	1	1.0	91.3
117.69	1	1.0	92.2
127.93	1	1.0	93.2
135.60	1	1.0	94.2
185.19	1	1.0	95.1
204.68	1	1.0	96.1
209.80	1	1.0	97.1
223.87	1	1.0	98.1
245.62	1	1.0	99.0
253.29	1	1.0	100.0
Total	103	100.0	

Table 4.2.6.3: Storage capacity classes frequency table

Storage Capacity Class	Frequency	Percent	Cumulative Percent
Very critical requirement	79	76.7	76.7
Critical	13	12.6	89.3
Sufficient	3	2.9	92.2
Optimum requirement	8	7.8	100.0
Total	103	100.0	

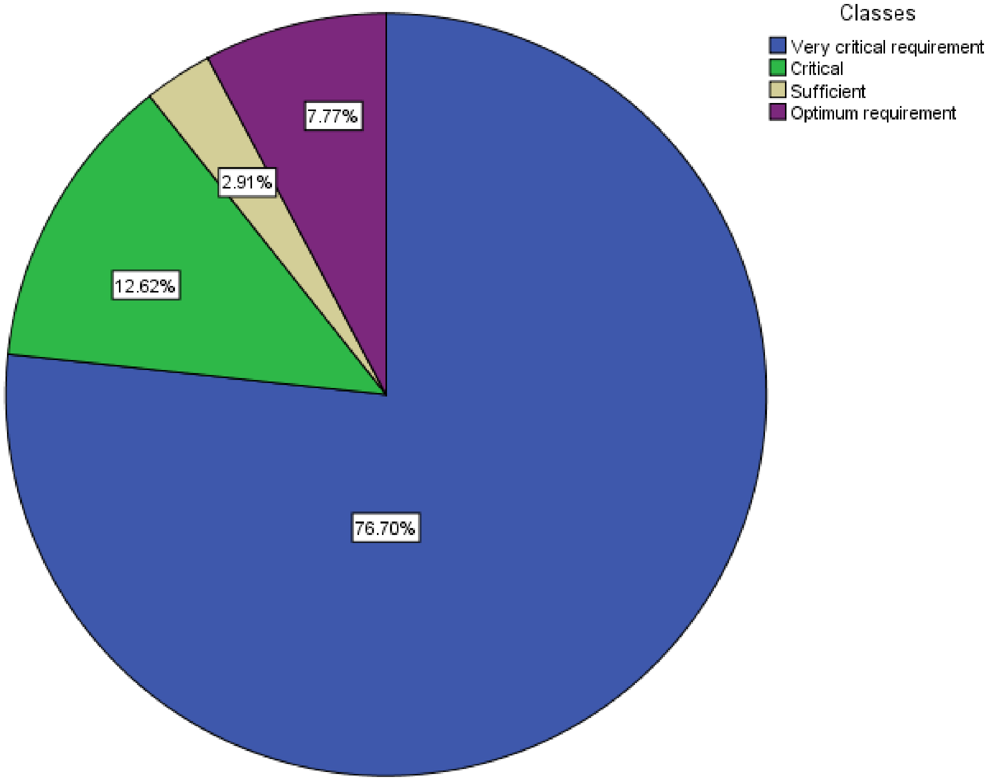


Figure 4.2.6: Pie chart on storage capacity ratio classes

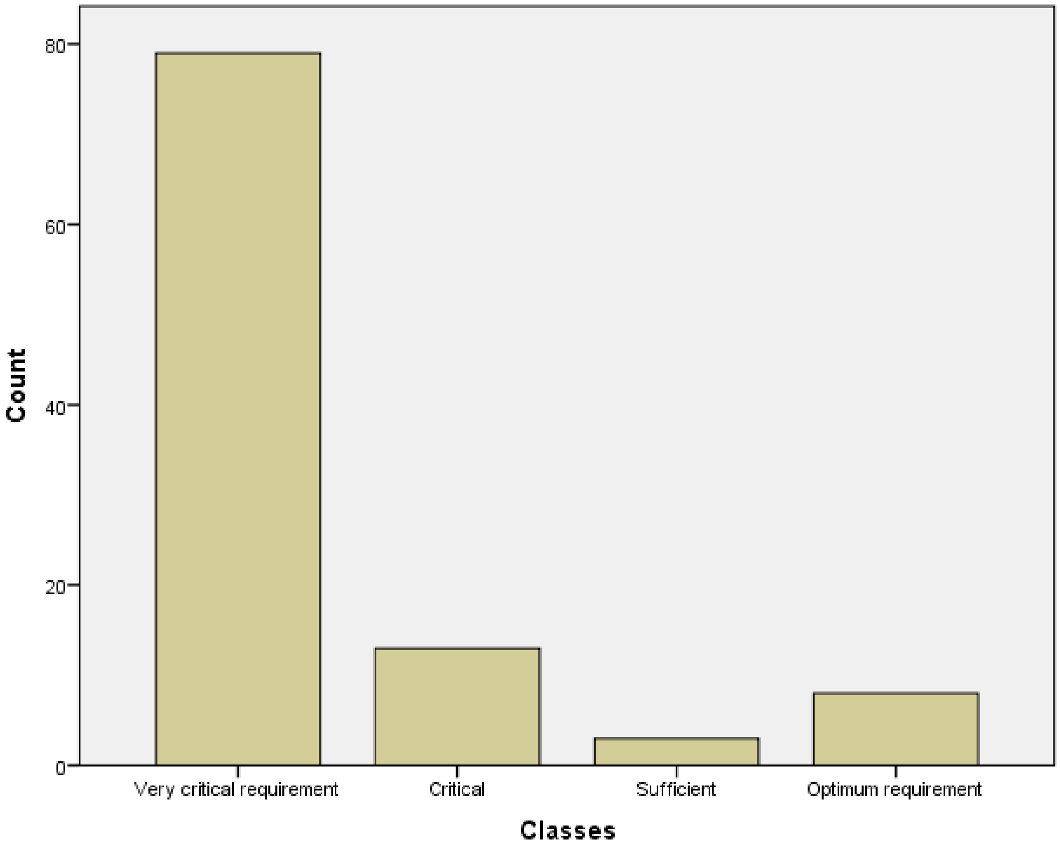


Figure 4.2.6.1: Bar chart on storage capacity ratio classes

From Tables 4.2.6, 4.2.61, 4.2.5.2, 4.2.6.3, and Figures 4.2.6, 4.2.6.1, 4.2.6.2 it is observed that 76.70% of the household roof water harvesting storage capacities are classified as of very critical requirement, meaning there is a mismatch between the storage capacities and the potential runoff volume from the rooftop catchments which is not exploited. This can be attributed to lack of due design considerations during installation of rainwater harvesting systems.

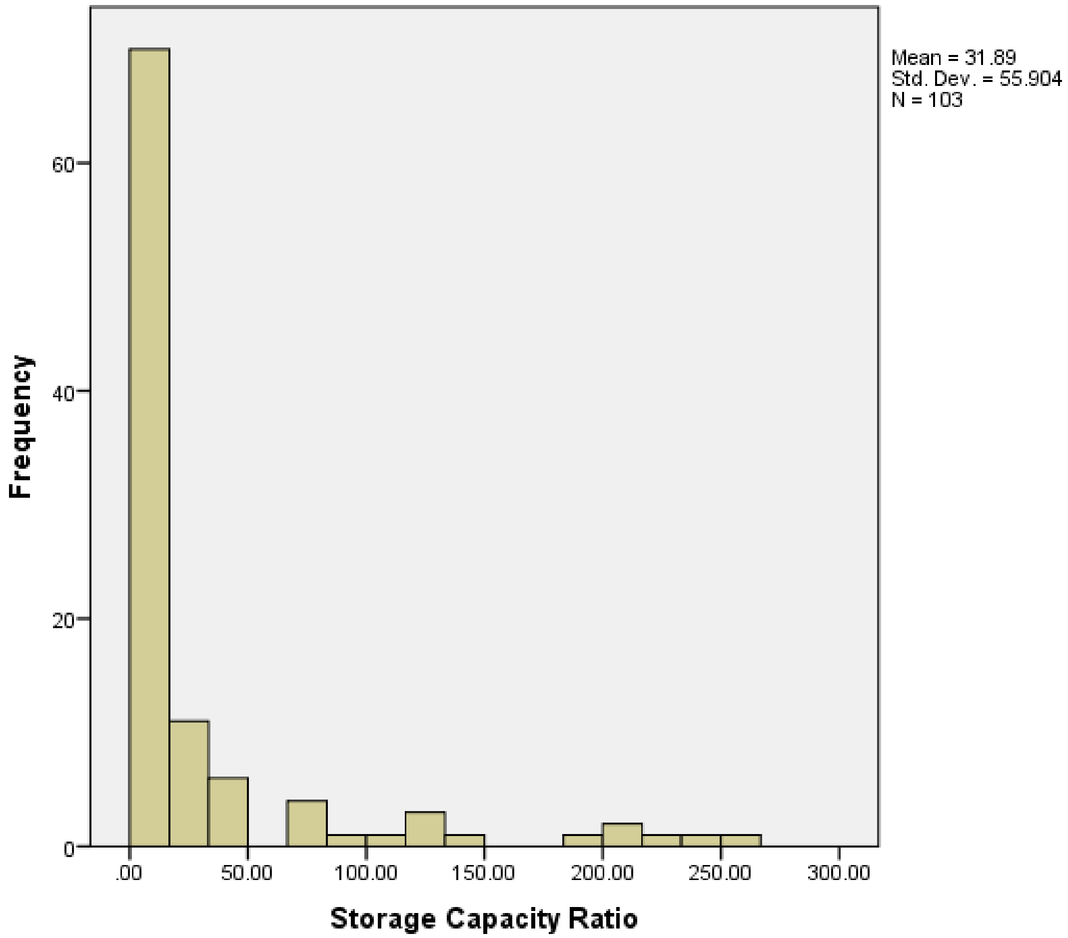


Figure 4.2.6.2: Histogram on storage capacity ratio classes

4.2.7 Farm Ponds

The uptake of farm ponds in the study area was insignificant since most of them did not have water for they were not lined with the recommended pond liners, they also lacked silt traps and spillways.The functional ponds were constructed with support from DRYDEP (Dry Land Development Programme), for demonstration purposes. The Table 4.2.7 below represents the characteristics of the farm ponds within the study area.

Table 4.2.7: Farm ponds characteristics

Characteristics/ Pond No.	Capacity (m^3)	Catchment Area,	Source of Pond Water	Lining	Shade Nets	Water Lifting	Fencing	Water Use
1.	250	2	Seasonal Water way	✓	✓	Solar Pump	✓	Vegetable farming
2.	50	1	Grass land	None	None	None	None	Agroforestry
3.	80	3	Road Runoff	None	None	None	None	Dry- due to high water loss
4.	100	2	Road Runoff	None	None	None	None	Very little water
5.	250	1.5	Roof+ Road Runoff	✓	✓	Solar Pump	✓	Mixed farming
6.	120	1	Farm land	None	None	None	None	Watering livestock
7.	250	2	Cut off Drain/ Road Runoff	✓	✓	Solar Pump	✓	Mixed farming

The concept of "Reliability" is one of the most widely used performance evaluation criteria for RWHS.Checking for reliability for a modern farm pond, with a storage capacity of $250m^3$, to be used for growing of potatoes on 1/8 of an acre plot for one season results to the following tabulations;

Establishing Irrigation Water Requirements

The farm pond is used for supplemental irrigation of vegetable crops for household consumption and sale to the local market as a source of income for the beneficiaries. Under these circumstances a drip irrigation system was considered the most appropriate due to its high efficiency (80%) in water application. High value vegetable crops like tomatoes, kales and spinach, are grown. The crop water requirements are established as shown below;

Annual evaporation is 2200mm, using a pan coefficient of 0.8, then the reference evapotranspiration (Eto) will be 2200 x 0.8 = 1760 mm

The average monthly evapotranspiration will be 1760 / 12 = 146.67 mm

Crop to be grown: vegetables, length of total growing season: 90 days

ETo: average of 5.0 mm/day over the total growing season

Crop water Requirement: ET crop = kc x Eto

Values of Kc, for most crops Kc generally lies between 0.6 to 0.9, Doorenbos and Kassam (1979).

ET crop = 0.9 x 5 = 4.5 mm per day

ET crop = 4.5 x 90 days = approx. 405 mm per total growing season

Area to be under irrigation is 1/8 acre ($500m^2$)

Hence the volume of water required is = (500 x 405 /1000) m^3 approximately 202.5 m^3. Since the efficiency of the drip kit is 80%;

The volume of water required is (202.5 /0.8) m^3 = 253.125m^3

Reliability Ratio = Demand/ Storage = 253.125/ 250 = 1.0125 , using the decision table 4.2.8 below;

Table 4.2.8: Reliability Decision Table

Reliability ratio	Class	Value
Reliability ratio (-), the ratio between the total demand and the total supply of water. High suitability scores for the ratio are close to one	Sufficient (required water is largely less than supply)	< 0.35
	Medium Sufficient	0.35–0.75
	High Sufficient	0.75–1.1
	Large deficit	1.1–1.75
	Very large deficit (required water is largely higher than supply)	>1.75

Source: (Adham, et al., 2016)

Then the author concludes that the modern farm pond will be classiffied as of high sufficiency since its calculated reliability ratio is 1.0125 and within (0.75 – 1.1) range.

It was also observed that all the visited water ponds overflow during rainy season, an indication that the catchment yields were more than sufficient, and potential to increase size of the farm pond storage volumes.Further, most of the implemented modern farm ponds are within Waita location and there is need to construct more demonstration farm ponds in the other locations within Mwingi Central Sub-County , to enhance increased uptake of the technology.

4.3 Cost Benefit Analysis of Rainwater Harvesting Structures

Benefits and costs associated with water projects occur at various times. Initial investment costs occurring at the beginning of the project life are associated with construction or implementation. Operation and maintenance costs continue throughout the life of the project. To achieve this objective, the Benefit Cost Ratio, Net Present Value and Internal Rate of Return, were used for analysis.

Equation

$$A = P\left(\frac{i(1+i)^N}{(1+i)^N - 1}\right)$$

The above discounting formula convert cash flows between a present amount P, and uniform annual series A. The factors within the parenthesis are a function of the annual interest or discount rate i and number of compounding periods (Years) N. Economic life of water tanks is taken as 15 years. Respective cost reduction or savings if water was to be purchased are calculated per household under investigation. For the below Mathematical Model discount rate i is taken as 10%

and the cost of 20litres of stored harvested rain water is estimated at KES 25 within the study area which is a conservative figure.

Notation form

A = P (A/P, i, N)

Factors in parenthesis – Capital Recovery

4.3.1 Cost Benefit Analysis of a Roof Rainwater Harvesting System

Table 4.3.1 below captures the annual capital recovery and respective benefits associated as a result of establishment of RWHS.

Table 4.3.1: Cost benefit analysis of a roof rainwater harvesting system

P	N	A (Capital Recovery) (KES)	Benefit/Savings (KES)
200000	15	26294.75538	50000
52000	15	6836.636398	12500
200000	15	26294.75538	62500
250000	15	32868.44422	62500
23000	15	3023.896868	15000
50000	15	6573.688844	12500
190000	15	24980.01761	75000
85000	15	11175.27104	25000
37000	15	4864.529745	12500
7600	15	999.2007043	2500
100000	15	13147.37769	37500
25000	15	3286.844422	12500
15000	15	1972.106653	7500
350000	15	46015.82191	250000
200000	15	26294.75538	50000
35000	15	4601.582191	12500

250000	15	32868.44422	80000
14000	15	1840.632876	6250
40000	15	5258.951075	15000
100000	15	13147.37769	25000
10000	15	1314.737769	5750
35000	15	4601.582191	12500
500000	15	65736.88844	456250
750000	15	98605.33267	375000
250000	15	32868.44422	65000
150000	15	19721.06653	25000
240000	15	31553.70645	50000
500000	15	65736.88844	75000
8500	15	1117.527104	5750
5000	15	657.3688844	3750
15000	15	1972.106653	6250
20000	15	2629.475538	8750
38000	15	4996.003522	12500
140000	15	18406.32876	80000
135000	15	17748.95988	62500
15000	15	1972.106653	18750
350000	15	46015.82191	200000
51000	15	6705.162621	20000
6000	15	788.8426613	3500
21000	15	2760.949315	8750
16000	15	2103.58043	7500
17000	15	2235.054207	8000
40000	15	5258.951075	15000
65000	15	8545.795498	25000
16000	15	2103.58043	7500
45000	15	5916.31996	22500
75000	15	9860.533267	25000

180000	15	23665.27984	112500
140000	15	18406.32876	50000
6500	15	854.5795498	2500
18000	15	2366.527984	7500
16000	15	2103.58043	8750
35000	15	4601.582191	12500
10000	15	1314.737769	3750
18000	15	2366.527984	7500
15000	15	1972.106653	6250
120000	15	15776.85323	26500
88000	15	11569.69237	32500
34000	15	4470.108414	12500
38000	15	4996.003522	12500
360000	15	47330.55968	125000
65000	15	8545.795498	25000
125000	15	16434.22211	50000
36000	15	4733.055968	12500
67000	15	8808.743051	25000
140000	15	18406.32876	50000
97000	15	12752.95636	37500
21000	15	2760.949315	7500
75000	15	9860.533267	25000
36000	15	4733.055968	12500
35000	15	4601.582191	12500

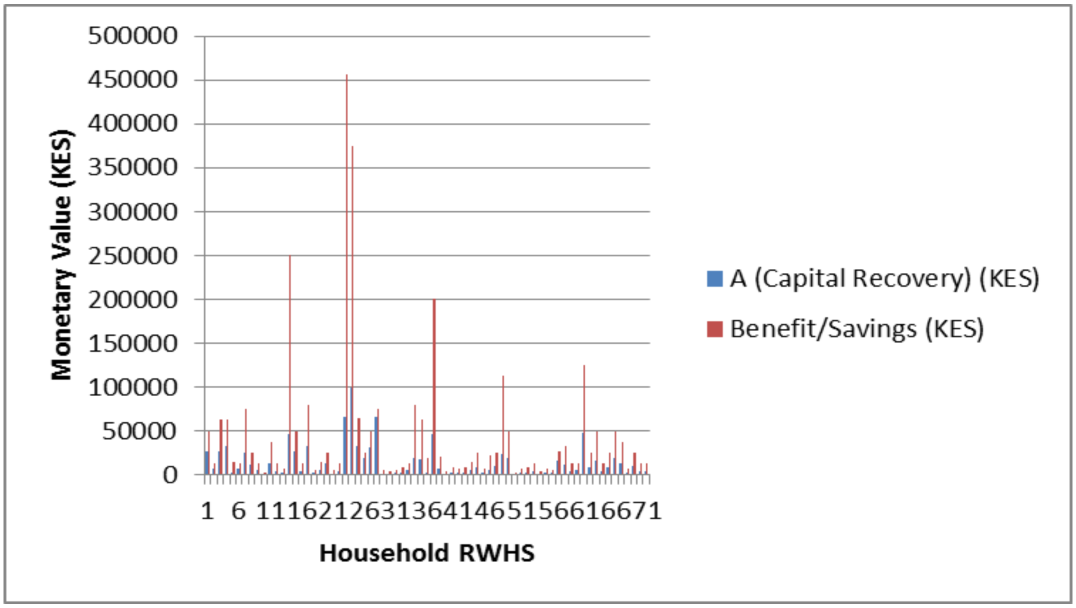


Figure 4.3.1: Bar Chart representing costs benefit analysis of roof rainwater harvesting systems

By use of the above model and as reflected in figure 4.3.1, it was established that the benefits of Roof water harvesting structures are much more worthy than the initial cost of the investment and maintenance of the structures.

4.3.2: Cost Benefit Analysis of a Farm Pond

Table 4.3.2: Costs of establishing a farm pond

Costs

S/NO.	Item	Cost (KES)
1.	Pond excavation works 3m deep by 16m by 10m	80,000
2.	Lining Material gauge 0.75mm	200,000
3.	Evaporation prevention net	70,000
4.	Fencing posts	40,000
5.	Cement, 15 bags @ 700	10500
6.	Labour	3,000
7.	80 watts solar panel + solar pump (Future solar pump)	246500
	Total	650,000

Source: DRYDEP demonstration farm pond

Assume annual Maintenance costs of KES 25,000

Benefits

Yield: 45 tons/ha - 65 tons/ha, assuming 45 tons/ha , this translates to 2250kgs per 1/8 of an acre.

The market Price of 1 kg of tomatoes is 100/= within the study area markets,

Sales: 2250kgs * 100/=, approximately KES 225,000 per season

Variable costs: Assumed to be approximately KES 125,000

Sell tomatoes at KES 100,000 profit per season, per year yielding KES 200,000 profit.

Table 4.3.2.2: Cost benefit analysis of a farm pond

P	N	A (Capital Recovery) (KES)	Benefit/Savings (KES)
675000	10	109853.1415	200000

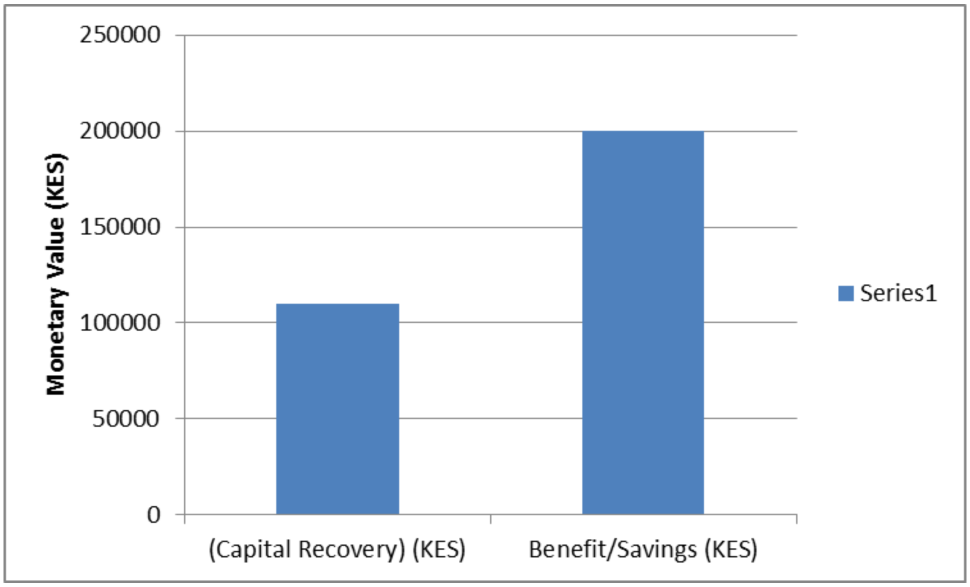


Figure 4.3.2: Cost benefit analysis of a farm pond

Hence as per table 4.3.2.2 and figure 4.3.2 above it is concluded that, it is economically viable to invest on a modern farm pond for production of high value crops like tomatoes, onions, and watermelon commonly grown in the study area using farm pond water.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are made from the study;

1. The key water harvesting technologies prevalent in the study area are Roof catchment tanks, farm ponds; earth dams/water pans, shallow wells mostly dug in sandy seasonal rivers, sub-surface dams / sand dams, Rock catchments both natural and manmade and boreholes. However, roof RWHS has the highest use in the study area.

2. Most of the community watering points are not performing as expected due to design and management challenges.

3. Roof tank capacities or storage do not meet the expected or theoretically computed tank sizes

4. The existing farm ponds are not producing significant impact due to design limitations. However, the demonstrations farm ponds have satisfactory levels of reliability.

5. Household rainwater harvesting is key to enhancing levels of water security in the study area, its potential has not been fully realized.

6. Further, it can be concluded that rainwater harvesting boosts water accessibility for both domestic consumption and farming needs in arid and semi-arid environments.

7. The author of this report concludes that rainwater harvesting is an economically viable method of providing water to households in the study area and those also under similar environments in Kenya.

8. The research outcomes offer a foundation on which engineers and managers can construct effective RWH structures meeting the purposes of the people living in areas characterized by high levels of water insecurity.

5.2 Recommendations

The following recommendations can be deduced from the study;

1. There is great need for government's investment in training activities that will promote awareness within the Mwingi population to better understand the benefits of the rain water harvesting technology. Residents should be educated and sensitized on the most effective ways of harvesting rainwater in the study area.

2. More effort and focus need to be directed at promoting the uptake of RWH technologies at household level, so as to alleviate the effects of the unpredictable nature of rainfall in the study area.

3. Due to persistent poverty levels in the study area Government and non-governmental support in funding the construction works, for water harvesting structures are highly welcome. This can be achieved through construction of more earth dams along the many available seasonal rivers and waterways.
4. Rehabilitation and expansion of rainwater harvesting structures is a key measure to increase the volumes of water under storage.
5. The county government and the local community also need to rehabilitate and maintain the rural access roads leading towards the major community watering points to facilitate safe access to them.
6. There is need for further study to establish the water quality of the communal water points.

REFERENCES

Alamerew E, (2006). *Towards Widespread Rainwater Harvesting in Ethiopia: ERHA's experience as a successful Rainwater Harvesting Capacity Centre (RHCC).* In '10th Southern and Eastern Africa Rainwater Network (SearNet) International '. Mombasa, Kenya. (Ed. KG Sectetariat).

Adham A., Michel R., Mohamed O. and Coen J. R. (2016). A Methodology to Assess and Evaluate Rainwater Harvesting Techniques in (Semi-) Arid Regions. *Journal of Water*, Vol. 8, Issue 5, 198; doi:10.3390/w8050198. Retrieved on April 5, 2018, from http://www.mdpi.com/journal/water.

Aroka, N, (2010). *Rainwater Harvesting in Rural Kenya. Reliability in a Variable and Changing Climate*. Master's Thesis, Stockholm University, viewed 12 October,2*014*,https://www.divaportal.org/smash/get/diva2:354235/FULLTEXT02.pdf

Arun, K.D. & Sudhir, S.B. (2009). Domestic Rooftop Water Harvesting: A Case Study. *ARPN Journal of Engineering and Applied Sciences*. Vol. 4, No. 6.

Bazza, M. & Tayaa M. (1994). *Operation and Management of Water Harvesting Technique*s. In Water Harvesting for Improved Agricultural Production. Proceedings of the FAO Expert Consultation, Cairo. Water Report No.3:271-283.

Biswas, B.K. & Mandal, B.H. (2014). Construction and Evaluation of Rainwater Harvesting System for Domestic Use in a Remote and Rural Area of Khulna, Bangladesh. Hindawi Publishing Corporation. *International Scholarly Research Notices.* http://dx.doi.org/10.1155/2014/751952.

Chow, V.T., Maidement D.R & Mays, L.W. (1988). *Applied Hydrology.* Publisher, McGraw-Hill Book Company, New York. Series in Water Resources and Environmental Engineering, 572p. Retrieved on August 08, 2018, from http://hydrology.usu.edu/dtarb/cee3430/2011/CurveNumberMethod.pdf.

Cochran, W.G. (1977). *Sampling Technique,* (3rd Edition). John Wiley & Sons, New York. Retrieved on February 20,2018, from; https://hwbdocuments.env.nm.gov/Los%20Alamos%20National%20Labs/General/14447.pdf.

Development Technology Unit (1987). *Domestic Roof-water Harvesting Research Programme*. University of Warwick School of Engineering. Retrieved on March 15,2018, from http://www.eng.warwick.ac.uk/DTU/rwh/index.html Encyclopedia.

Dr. Hofman, IR.J.A.M.H. & Dr. Paalman, IR.M. (2014). *Rainwater Harvesting: A Sustainable Solution for Urban Climate Adaptatio*n. KWR Watercycle Research Institute: Nieuwegein, The Netherlands.

Fentaw, B., Alamerew, E. & Ali, S. (2002). *Traditional Rainwater Harvesting Systems for Food Production*. The Case of Kobo Wereda, Northern Ethiopia.

Fewkes, A. & Warm P. (2000). Method of Modelling the Performance of Rainwater Collector Systems in the United Kingdom. *Building Services Engineering Research and Technology*, (2): 257-265.

Finkel, H.J. & Finkel, M. (1986). *Hydrology*. In: Finkel H.J. (ed.). Semi-Arid Soil and Water Conservation. CRC Press Inc.: 5-26

Girma, M.K, (2009). *Identification of Potential Rainwater Harvesting Areas in the Central Rift Valley of Ethiopia using a GIS-based Approach*. MSc thesis Wageningen University, The Netherlands, *viewed 20 November 2015*,https://www.wur.nl/.../e36238b5-a639-499c-b28e-643b7ba4ac72_GirmaKetselathesis

Gould, J., (1999). *Contributions Relating to Rainwater Harvesting. Contributing Paper*. World Commission on Dams: New Zealand.

Hudson, N.W., (1987). Soil and Water Conservation in Semi-arid areas. Soil Resources, Management and Conservation Services. *FAO Land and Water Development Division,* No. 57.

Huizing, A., (1988). *Rainfall-Runoff Relations in a Small Cultivated Valley in Sierra Leone. Wetland Utilization Research Project*. International Institute for Land Reclamation and Improvement. Wageningen: The Netherlands.

Jungsoo, M., & Mooyoung, H., (2012). Design and Operational Parameters of a Rooftop Rainwater Harvesting System; Definition, Sensitivity and Verification. *Journal of Environmental Management* 93(1):147-53.

Kahinda, J. Mwenge, Taigbenu A. E., & Boroto R.J., (2010). Domestic Rainwater Harvesting as an Adaptation Measure to Climate Change in South Africa. *Journal Physics and Chemistry of the Earth* 35 (2010) 742–751.

Maimbo, M..M, Sang, J.K., Oduor, A.R. Odhaimbo J.O. & Nyabenge, M. (2006). *Hydrologic Impacts of Ponds on Land Cover Change: Runoff Water Harvesting in Lare, Kenya*. Technical Report No. 32 Nairobi, Kenya: Regional Land Management Unit (RELMA-in-ICRAF), Netherlands Ministry of Foreign Affairs and Swedish International Development Cooperation Agency (Sida).

Martin, T.M. (2009). *An Analysis of Household Rainwater Harvesting Schemes in Falelima, Samoa*. Master’s Report, Michigan Technological University. Assessed on March, 8 2018, http://docplayer.net/4190311.

Mati, B., Bock, T.D., Malesu, M., Khaka, E., Oduor, A., Nyabenge, M., & Oduor, V. (2006). *Mapping the Potential of Rainwater Harvesting Technologies in Africa: a GIS Overview on Development Domains for the Continent and Ten Selected Countries*. Technical Manual No. 6. World Agroforestry Centre (ICRAF), Netherlands Ministry of Foreign Affairs, Nairobi, Kenya.

Mati, B. M., Malesu, M. & Oduor, A. (2005). *Promoting Rainwater Harvesting in Eastern and Southern Africa*. The RELMA Experience.

Mariappan, P. (1990). *Estimation of Infiltration in Changing Land Use Pattern Using SCS Curve Number Technique*. M.E Thesis, Anna University, Chennai.

Ngigi, S.N., Thome J.N., Rockstrom J., Penning de Vries F.W.T., & Savenije H.H.G. (2005a). Agro-hydrological Evaluation of On-Farm Rainwater Storage Systems for Supplemental Irrigation in Laikipia District, Kenya. *Agricultural Water Management, 73*(1): 21-4. Available online at www.sciencedirect.com.http://www.elsevier.com/locate/agwat.doi:10.1016/j.agwat.2004.09.021.

Ngigi, S.N., Savenije, H.H.G., Rockstro¨m, J., Gachene C.K., (2005b). *Hydro-*Economic Evaluation of Rainwater Harvesting and Management Technologies: Farmers Investment Options and Risks in Semi-Arid Laikipia district of Kenya. *Journal Physics and Chemistry of the Earth* 30 (1) 772–782. Available at:

http://www.elsevier.com/locate/pce. doi:10.1016/j.pce.2005.08.020.

Nissen-peterssenn, E, (2006). *Water from Dry Riverbeds*. ASAL Consultants Ltd. for the Danish International Development Agency (DANIDA) in Kenya. Technical handbook No. 24. Nairobi. Available online on http://www.faoswalim.org/resources/water/Water_for_arid_land/Water_from_dry_riverbeds.pdf

Olaoye Rebecca A., Coker Akinwale O.I, Sridhar Mynepalli K. & Adewole, E.M. (2013). Examining the Effectiveness of Rainwater Collection Systems in a Nigerian Leper Colony Using the Behavioural Model. ARPN *Journal of Engineering and Applied Sciences. Vol. 8*, No. 1. ISSN 1819-6608. www.arpnjournals.com.

Oweis, T.Y. & Hachum, A. & Kijne, J, (1999). Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas. *System- Wide Initiative on Water Management.* SWIM Paper No.7.

Palmer W. L., Barfield B. J. and Haan C. T. (1982). Sizing Farm Reservoirs for Supplementing Irrigation of Corn-Part 11. *Economic Analysis. Transactions of the ASAE*, Vol. 25 (2): 377-380.

Prienz, D. & Singh, A, (2001). *Technical Potential for Improvements of Water Harvesting. Contributing Paper*. World Commission on Dams: Cape Town, South Africa.

Reij C., Mulder, P. and Begemann L. (1988). Water Harvesting for Plant Production. *World Bank Technical Paper* No. 91.

Senay, G.B. & Verdin, J.P, (2004). Developing Index Maps of Water−Harvest Potential in Africa. *Applied Engineering in Agriculture* 20, 789−799.

Stott, D.E., Mohtar, R.H., Steinhardt, G.C. (2001). *Water Conservation, Harvesting and Management* (WCHM). Kenyan Experience.

Tam VWY, Tam L, Zeng SX (2010). Cost Effectiveness and Tradeoff on the Use of Rainwater Tank: An Empirical Study in Australian Residential Decision-Making. *Resources, Conservation and Recycling*; *54*:178–86.

UNEP. (1983). *Rain and Storm Water Harvesting in Rural Areas*. Tycooly, Dublin. Ireland.

United Nations Environmental Programme (1997). *Rainwater Harvesting from Rooftop Catchments*. Retrieved from The Sourcebook of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. Retrieved, on December, 12. 2007, from, www.oas.org/usde/publications/unit/oea59e/ch10.htm. Weatherall.

APPENDICES

Appendix A : Questionnaire

Appendix A1 : Consent Form

Dear Sir/ Madam

My name is Steve Ngonda Matiti currently working for Ministry of Agriculture and deployed as District Agricultural Engineer, Limuru.

I am currently pursuing a post graduate degree, MSc. Environmental and Bio-Systems Engineering at the University of Nairobi. In partial fulfillment of the requirements of the course, am to submit a research thesis report. It is for this purpose therefore, that I propose to carry out a study on your institution.

The purpose of this study is to evaluate the performance of RWH technologies in Mwingi Central, Sub-County. The aim of the study is to analyze and document the adopted interventions with a view of up scaling successful efforts and mapping of existing major water harvesting sites.

It is anticipated that findings of this study will contribute to making informed decision regarding choice or selection of appropriate RWH technologies. The vision of transforming Kenya into a water secure Nation by the year 2030 is critically hinged upon sustainable water management. The implementation of water harvesting interventions will contribute greatly towards the achievement of this goal.

For this purpose, I am kindly asking you to fill in the attached questionnaire as honestly and objectively as possible. This will help in the identification of intervention areas by key stakeholders in the integrated water resources management sector. All information provided will be treated in strict confidence and will only be used for the purposes of analysis for the study.

Appendix A2: Household Questionnaire

Performance evaluation of rainwater harvesting technologies in Kavuvwani Location Mwingi Central Sub-County.

A: General information

1. Household Reference No……………………

GPS Location of household…………..

Latitude……………………….Longitude………………………….

2. Sex of the respondent: Male ( ); Female ( ) Tick appropriately

3. Education level of respondent

a. None ( ), b. Primary ( ); c. Secondary ( ), d. Tertiary ( ) Tick appropriately

4. Total family size……………………….

5. Rate the level of water availability for both domestic and agricultural use at your farm.

   a. Scarce ( )
   b. Moderate ( )
   c. Adequate ( )
   d. Very adequate ( )

B: Existing Rain Water harvesting technologies and Mapping of Key watering Points

6. list the main community watering points within your reach in the location.

I………………………………………………………………………………………

ii……………………………………………………………………………………

iii……………………………………………………………………………………..

iv……………………………………………………………………………………..

7. Select the main challenge you face in the existing community watering points

a. Saline water source ( )
b. Poor rural access roads ( )
c. Polluted and silted water sources ( )
d. Long distances to the water sources ( )
e. Conflicts due to water scarcity ( )
f. Insecure watering points ( )
g. Drying up of water sources due to persistent drought conditions ( )

8. Tick the forms of rainwater harvesting technology practiced at household level

a. Roof ( )
b. Farm pond ( )
c. Well ( )
d. Roof + Well ( )
e. None ( )
f. Farm pond +well ( )
g. Farm pond +roof +well ( )

9. What is the main cause of low adoption of rainwater harvesting technologies at household level?

a. Low income ( )
b. High cost of storage tanks and farm ponds ( )
c. Limited knowledge and skills on rainwater harvesting technologies ( )
d. Unreliable rainfall patterns ( )

e. Water losses from storage facilities (Leaking tanks, high pond seepage rates) ( ),

10. List the key stakeholders actively involved in community water supply in the study area?

i. ……………………………………………………………………………………….

ii. ……………………………………………………………………………………….

iii. ………………………………………………………………………………………

iv. …………………………………………………………………..……………

11. Types of Storage Tanks used at individual household level

a) Ferro cement ( )

b) Concrete/ Reinforced Concrete ( )

c) Plastic ( )

d) Bricks (Masonry) ( )

e) Mettalic ( )

f) None ( )

C: Evaluate Performance of selected existing rainwater harvesting technologies in the study area

12. Roof Area ………………………………………..……………….

13. Tank Volume (Capacity)…………………………………….…..………………

14.Is storage capacity adequate or in adequate……………………….………….

15. Is the water harvesting system designed technically…………………………...

16. Are the existing roof catchments adequately guttered………………………...

17. Is there a match or mismatch between catchment area and storage capacities …………………………………………………………………………………………

18. Farm ponds characteristics

i. Farm pond capacities, ………………………………….…………………..

ii. catchment sizes ……………………………………………………….

iii. source of the farm pond water,…………………………….……….…….

iv. lining of the ponds to control seepage, …………………….……………..

v. covering with evaporation control nets, …………………….…………….

vi. type of water lifting system used to draw water from the pond, …………..

vii. incorporation of silt traps,…………………………………………………

viii. fencing of the ponds …………………………………………………….

ix. usage of the pond water………………………………………………….

D: Economic Analysis of selected water harvesting technologies currently in place at the selected area

19. Initial investment cost – The cost of existing size of storage, plus related system installation costs…………………………………………………..…………………

20. Monetary value of harvested rain water- Cost per 20 liters' of volume of water harvested……………………………………………………………..…………

21. Maintenance costs incurred? …………………..……………………………

22. Volume of Water Harvested / season/year……………………………………..

23. Life span of the water storage system in years ……………………….…………

24. Other economic use of the harvested water at household level e.g – Kitchen gardening, small scale irrigation farming – (Economic Value in KES)……………………………………………………………………..………

Appendix A3: Key informers Interview Questionnaire

Key informers/ Focused Group Discussion / Institutional Questionnaire

1 Ref No……………………Sub Location ……………………………………

2.Name of the organization…………………………………………………

The main causes of water shortages in the location?

Which are the key reasons of recurrent water scarcity in Kavuvwani location?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Which are the water scarcity managing approaches?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

How can water scarcity challenge be resolved?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

What are the key rain water harvesting technologies in this location?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

What key actions aimed towards increasing the implementation of rainwater harvesting technologies in Kavuvwani location need to be upscaled?

i. ……………………………………………………………………………………
ii. ……………………………………………………………………………………
iii. ……………………………………………………………………………………

What are the obstacles to investment in rain water harvesting technologies?

i. ……………………………………………………………………………………
ii. ……………………………………………………………………………………
iii. ……………………………………………………………………………………

How can you address the above obstacles mentioned above at your level?

i. ……………………………………………………………………………………
ii. ……………………………………………………………………………………
iii. ……………………………………………………………………………………
iv. ……………………………………………………………………………………

Who are the key stakeholders involved in implementation of water harvesting systems or technologies in the study area

i. …………………………………………………………………………………….
ii. …………………………………………………………………………………….
iii. …………………………………………………………………………………
iv. ………………………………………………………………………………

Mention the major key community watering points in the study area

i. …………………………………………………………………………………….

ii. …………………………………………………………………………………….

iii. …………………………………………………………………………………

iv. ……………………………………………………………………………………

What challenges face the existing community watering points

i. …………………………………………………………………………………….

ii. …………………………………………………………………………………….

iii. ……………………………………………………………………………………

iv. ……………………………………………………………………………………

How can the above mentioned challenges be addressed

i. …………………………………………………………………………………….

ii. …………………………………………………………………………………….

iii. ……………………………………………………………………………………

iv. ……………………………………………………………………………………

Appendix B: Mwingi Central Rainfall Data

Mwingi Central Rainfall												
YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1986												
1987	36.1	0	16.4	170.3	2.5	5.1	0	7.9	0	0	179.3	0.2
1988	58.3	14.3	0.3	144.12	76.9	0	0	3.1	7.6	31.6	224.3	240.1
1989	115.9	58.3	3.1	48.1	311.9	42.1	3.1	0	0	0	45	299
1990	262.9	71.8	51.5	185.3	210.8	26.2	0	0	0	0	190.7	216.6
1991	232.5	9.5	0	94.8	74.4	25.1	0.2	19.5	24.4	0	54.4	173.4
1992	200.7	8	0	5.3	143.7	1	0	0				
1993	206.5	13.2	0	70.7	42.3	0	0	0	0	50.5	117.9	26.4
1994	0	0	10.3	5.2	118.6	16.1	0	0	0	0	21	193.1
1995		0	34.2	39.7	47.1	0	0					
1996										134	511	390
1997												
1998												
1999												
2000												
2001	55.6	8.1	4.7	126.4	0	0	6.4	0	0.5	0	0	303.7
2002	0	72.5	43.5	121.5	0	0	0	0	4.5	8.2	202	214.2
2003												
2004	86.4	17.8	3.5	10.7	0	0	0	0	0	0	92	440
2005	30	0	40	184.8	13	0	0	0	0	0	34	0
2006	32	23	36.5	8.2	17.4	12.5	0	0	0	39	548.8	205.2
2007	99	0	0	137.5	0	0	0	0	0	27	153.3	32.3

Mwingi Central Rainfall Data Cont'

2008	121.7	0	23.2	110.5	0.8	0	0.1	0.6	0	18.9	101.5	1.2
2009	54.1	5.3	0.6	57.6	5	1.6	0	0	0	115.6	128.4	104.2
2010	12.6	57.2	216.8	175.8	17.7	0	0	0	0	18.2	94	11.2
2011	1.8	39.6	62.8	17.4	21	0	0	0	0	195.7	318	63.2
2012	0	0	2.2	307.2	10.8	10.5	0	7.6	0	4.2	137.1	150.9
2013	18.9	0	77	140	0	0	0	0	0	0	15.5	84.2
2014	0	55.3	64.1	85.5	0	0	0	0	0	23.4	223.4	43.5
2015	0	0	108	85.6	4.3	0	0	0	0	0	284	197.7
2016	41.6	2.2	22.7	77.5	119.5	4	0	0	0	0	160.3	74.9
2017	0	0	0	65.7	28	0	0	0	0	59.4	246.5	0
2018	0	0	201.6	485.7								

Source: Mwingi Central Agricultural Meteorological Station ; Registration No. 9038008.

Appendix C: Plates

Plate 11: Shallow well at Tyaa Seasonal River

Plate 12: A woman fetching water from the tyaa seasonal river well

Plate 13: Kiia Earth Dam

Plate 14: Kavuvwani Borehole

Plate 15: Household Roof water harvesting

Plate 16: Kiia Rock Catchment water Kiosk

Plate 17: High rates of soil sedimentation in a water pan

Plate18: Household Roof water harvesting

Plate19: Water pans

Plate 20: Kasovi Earth Dam

Plate 21: Risky water point

Plate 22: Household Roof Waterharvesting

Plate 23: Kiio Rock Catchment

Plate 24: Mathungi Borehole Community Water Project

Plate 25: Kiio Rock Catchment storage

Plate 26: Farming along tyaa River Banks

Plate 27: Shallow well dug at Dry tyaa river bed and used for irrigating vegetables

Appendix D: Inventory of Water Sources

	INVETORY OF WATER SOURCES- MWINGI CENTRAL						
A.	**1.Boreholes equipped with motorised pumps**						
No.	**Name of b/h**	**Location**	**Total depth**	**Yield m^3/hr**	**Ownership**	**Pop. Served**	**status**
1	Bajamber	mwingi central	13.5	2.3	individual	40	operational
2	Mwingi Hospital	mwingi central	100	36	Hospital	1000	operational
3	Tyaa Kanginga Oasis	mwingi central	102	12	school	1500	operational
4	St. Josephs Seminary	mwingi central	60	0.16	school	600	operational
5	Kanzui	mwingi central	105	3.6	community	2000	operational
6	Misai	mwingi central	108	1.5	community	100	operational
7	Mwingi Modern market	mwingi central	120	2	community	800	new
8	Mumbuni	Mumbuni	74	25	community	5000	operational
9	Katalwa	Katalwa	93	5	community		stalled
10	Nzeluni Girls secondary	Mumbuni			school		new
11	Syokithusa	Kisovo	130	3.9	community	500	operational
12	Kyethani	Kyethani	80	18	community	3500	operational
13	Kiomo	Kiomo	102	2	community	4000	operational
14	Karura	Kyethani		3.8	community	1500	operational
15	Mbondoni	Kavuvwani		2.4	community	2500	operational
16	Kairungu	Kairungu	90	7	community	3000	operational
17	Nyamu Kimanzi	Kiomo			individual	individual	operational
18	Nguna Ngusya	Kairungu			individual	individual	operational
19	Kiio Catholic mission	Kairungu			church	100	operational
20	Mbondoni seconndary	Kiomo			school		new
	Boreholes equipped with hand pumps						
1	Kilulu	Kisovo	90	18		1000	operational
2	Kasovoni	Karung'a	91	3.6	community	2000	operational
3	Muruana	Karung'a		3.8	community	1000	operational

4	Kwa Kuvora	mwingi central	51	3	community	1200	operational
5	Wikithuki	Kyethani	51	0.9	community	800	operational
6	Kakongo	Kairungu	50	1.6	community	1200	operational
7	Kavauni	Kyethani	70	1.6	community	850	operational
8	Nzaaiku	Kyethani	70	1	community	500	operational
9	Kamunyu	Endui	72	1	community	600	operational
10	Ngondini	Kairungu	50	1.6	community	800	operational
B.	**Shallow wells equiped with hand pumps**						
1	Kivou 1	Mwingi central			Community	500	operational
2	Kivou 2	Mwingi central			Community	500	operational
3	Katalwa Ngwate Kwoko	katalwa			Community	1200	operational
4	Kwa Nungu	Mumbuni			Community	750	operational
C.	**Unequiped shallow wells**						
1	Kanginga				Individual		operational
2	Mangoloma				Individual		operational
3	Michael Musee				Individual		operational
4	John Musee				Individual		operational
5	Muli Kiunguu				Individual		operational
6	Nguna Kasina				Individual		operational
7	Mutisya Ngati				Individual		operational
8	Mue Muindu				Individual		operational
9	Mwinzi Mukuva				Individual		operational

D.	**Earth dams/rock catchments**	Location	**Storage capacity m³**	**Ownership**	**Pop. served**	**Status**
1	Kiiya	Enziu	20,000	Community	1200	operational
2	yamby r/c	Waita	15000	Community	900	operational
3	Kwa kasovi earthdam	Kavuvwani	18000	Community	2000	operational
4	Karung'a earthdam	Karung'a	10,000	Community	750	dry
5	Wisyuma r/c	Kiomo	5,000	Community	800	dry
6	Tivui r/c	Kavuvwani	5,000	Community	500	dry
7	Ndiuni ssd	Kairungu		Community	1000	operational
8	Itheng'eli ssd	Kisovo		Community	800	operational
9	Makutano e/d	Katalwa	10,000	Community	900	operational
10	Kisovo	Kisovo	10,000	Community		in-operational
11	Mutwathi e/d	Mumbuni	10000	Community	1500	dry
12	Karura ssd	Kyethani	Unknown	Community	1500	Operational
13	wikivuvwa ssd	Kairungu	unknown	Community	1500	Operational
14	mbondoni e/d	Kavuvwani		Community		dry
15	Kwamasi r/c	Kiomo		Community		dry
16	Kitema Earth dam	Katatwa	5000	Community	300	dry
17	Kiio r/c	Kairungu		Community		dry
18	Kalisasi r/c	Mumbuni		Community		dry
19	Tulanduli r/c	Kyethani	7000	Community	500	dry
20	Kianziani e/dam	Kairungu	1500	Community	950	operational

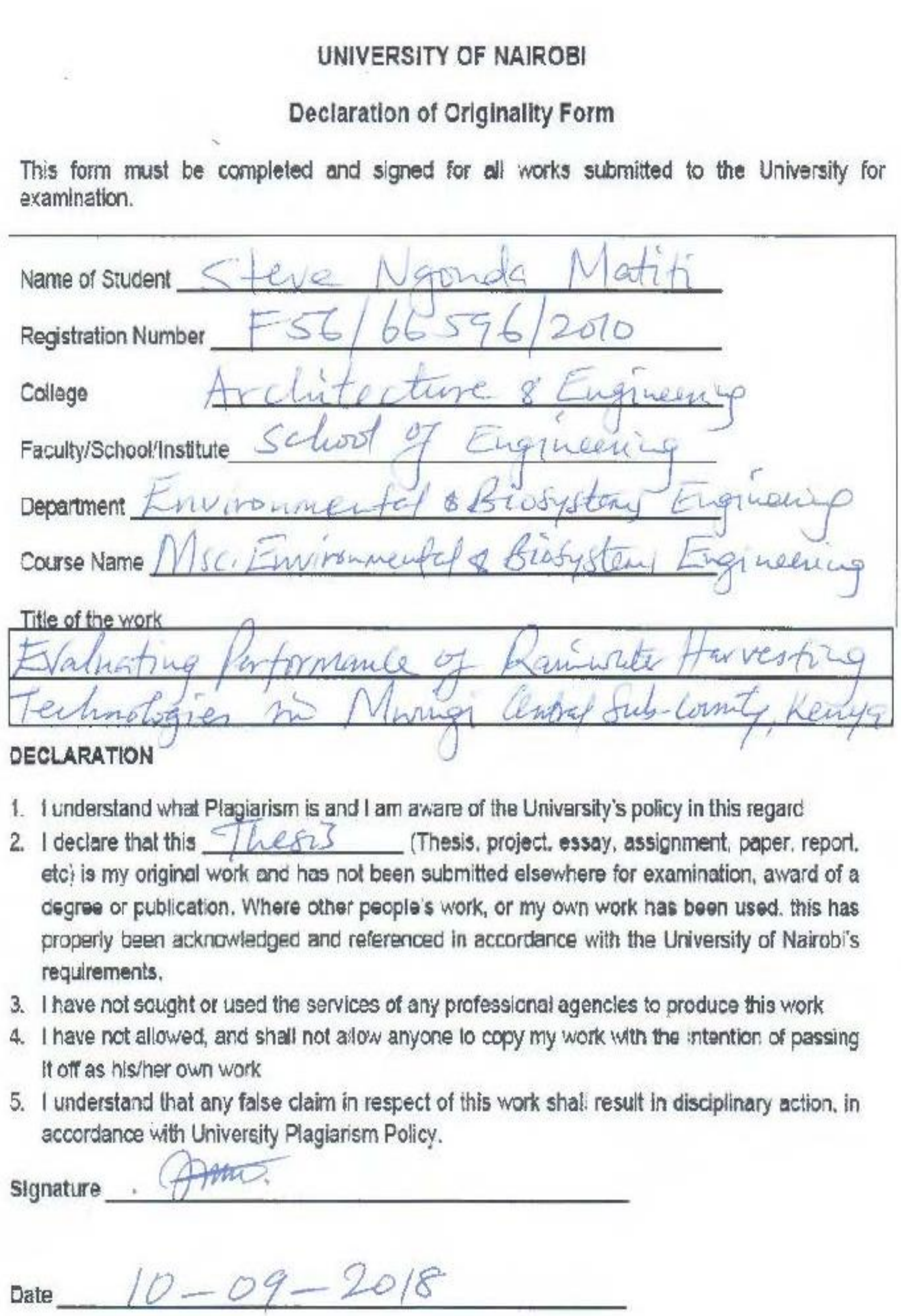
Appendix F: Characteristics of Some of the Mapped Water points

S/No.	Water Points	Latitude	Longitude	Remarks
1.	Kavuvwani Borehole	-0.98446	38.033885	Salty water
2.	Mung'etoni Kwa Kariavu	-0.976883	38.0389	Environmentally risky site
3.	Mutalia Borehole	-0.973567	37.996038	Private Borehole
4.	Tyaa River	-0.940732	38.0428002	Major source of Drinking water
5.	KIIA Earth Dam	-1.013587	38.01484	High sedimentation, lacks silt trap, catchment is cultivated
6.	Kanyonyoni Earth dam	-1.010095	38.009465	High sedimentation, lacks silt trap, catchment is cultivated
7.	KIIA Rock Catchment	-1.011978	38.016437	Major source of drinking water
8.	Misai Borehole	-1.011218	38.036532	Not currently functional
9.	Kiio Rock Catchment	-0.934322	37.958005	Major source of drinking water
10.	Mathungi Borehole	-0.968843	38.029125	Saline water, used for livestock watering
11.	Mwingi Water Supply	-0.932502	38.060013	Major source of

	Kiosk			drinking water
12.	Mumbuni Earth Dam	-0.997717	38.015073	High sedimentation, lacks silt trap, catchment is cultivated
13.	Tivui Rock Catchment	-0.9998555	38.006003	Unreliable, usually dry most of the time
14.	Kasovi Earth Dam	-0.995363	38.003672	High sedimentation, lacks silt trap, catchment is cultivated
15.	Mathungi Sand Dam	-0.970757	38.016193	Usually has water lasting for two months after rains.

Appendix G: List of Key Informants

S/NO.	NAME	ORGANIZATION	CONTACT
1.	Mwinzi Muvengei	Area Location Chief	0729349871
2.	Mwende Mutemi	Sub-location Assistant Chief	0729876756
3.	Simon Kaviu Mwinzi	Kavuvwani Village administrator	0724474298
4.	Joy K Ochieng	Mwingi Central Sub – county Agricultural officer	0728176035
5.	Mwendwa	Mwingi Central Sub – county irrigation officer	0725119101
6.	Johnson serem	DRY DEP	0732200830 / 0724415061



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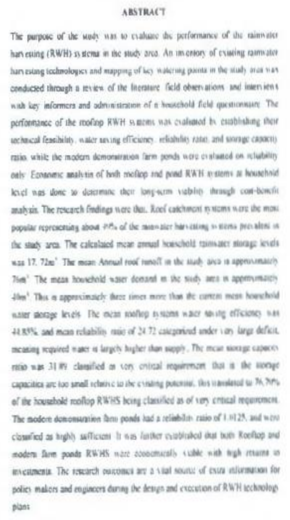
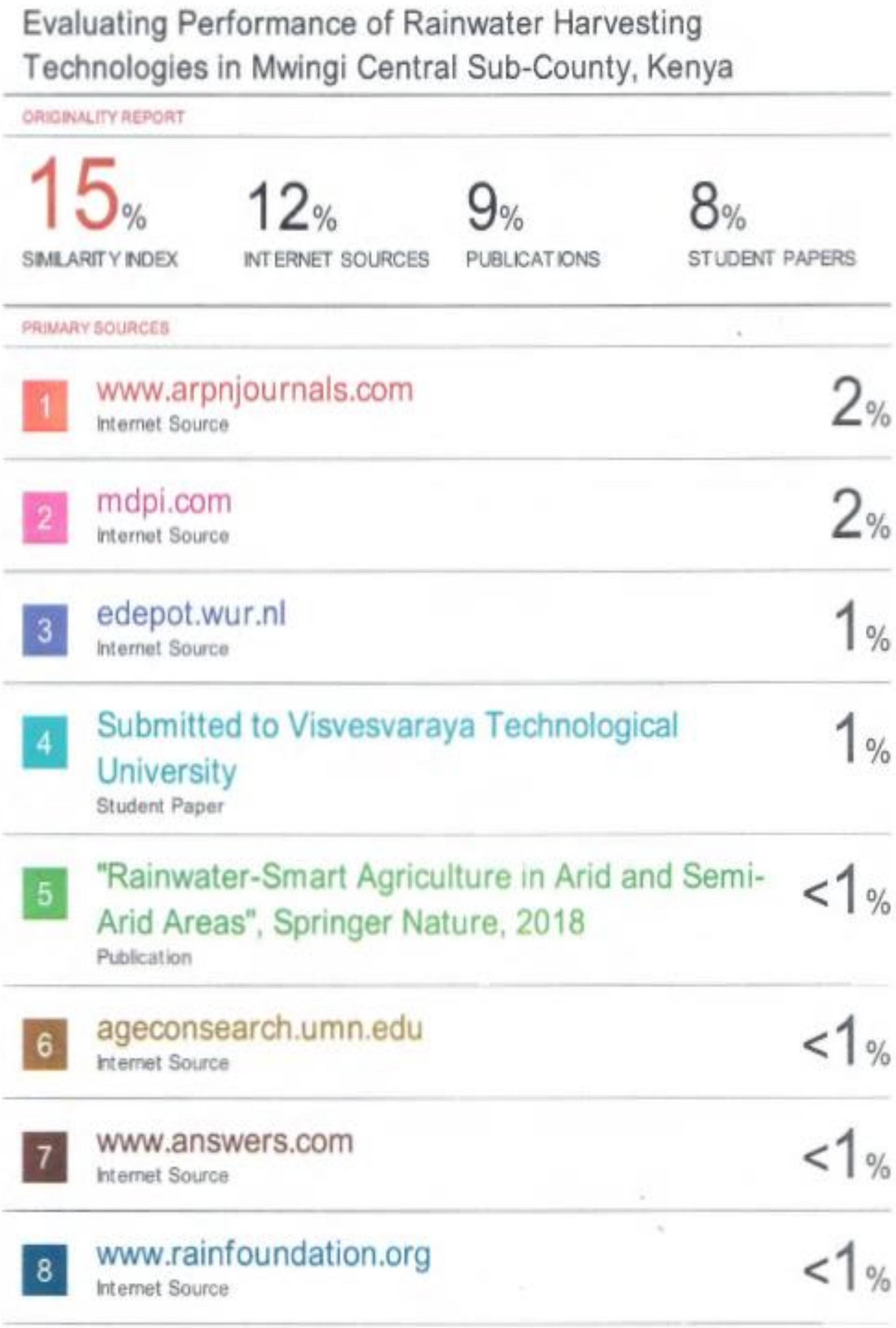


ABSTRACT

The purpose of the study was to evaluate the performance of the rainwater harvesting (RWH) systems in the study area. An inventory of existing rainwater harvesting technologies and mapping of key watering points in the study area was conducted through a review of the literature, field observations and interviews with key informers and administration of a household field questionnaire. The performance of the rooftop RWH systems was evaluated by establishing their technical feasibility, water saving efficiency, reliability ratio, and storage capacity ratio while the modern demonstration farm ponds were evaluated on reliability only. Economic analysis of both rooftop and pond RWH systems at household level was done to determine their long-term viability through cost-benefit analysis. The research findings were that, Roof catchment systems were the most popular representing about [illegible] of the rainwater harvesting systems prevalent in the study area. The calculated mean annual household rainwater storage levels was 17. 72m³. The mean Annual roof runoff in the study area is approximately 76m³. The mean household water demand in the study area is approximately 40m³. This is approximately three times more than the current mean household water storage levels. The mean rooftop systems water saving efficiency was 44.85%, and mean reliability ratio of 24.72 categorized under very large deficit, meaning required water is largely higher than supply. The mean storage capacity ratio was 31.89 classified as very critical requirement that is the storage capacities are too small relative to the existing potential, this translated to 76.76% of the household rooftop RWHS being classified as of very critical requirement. The modern demonstration farm ponds had a reliability ratio of 1.0125, and were classified as highly sufficient. It was further established that both Rooftop and modern farm ponds RWHS were economically viable with high returns to investments. The research outcomes are a vital source of extra information for policy makers and engineers during the design and execution of RWH technology plans



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