EFFECT OF IRRIGATION WATER ON SOIL CHEMICAL PROPERTIES AND RAIN WATER HARVESTING IN ISINYA, KAJIADO COUNTY

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DECLARATION

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

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ABSTRACT

Food insecurity is one of the major global problems that demands strategic intervention in the face of increasing human population and climate change upon the limited land and water resources. One strategy has been to open up more land in the arid and semi-arid lands (ASALs) for crop production through irrigation. Kenya has over 83% of the land mass in the ASALs. However, past research studies indicate that irrigation in ASALs faces challenges in availability, quality and quantity of irrigation water. Most sources of irrigation water in the ASAL include boreholes, wells and runoff water stored in water pans. The study was conducted in Isinya Sub County, Kajiado County with principal aim of promoting sustainability of dry land irrigation agriculture in Isinya Sub-County. Specific objectives were; (i) to determine the suitability and quality of irrigation water from boreholes and runoff water stored in dams, (ii) to determine the effect of the irrigation water on the soil chemical properties and (iii) to assess the amount of rain water that can be harvested from a typical greenhouse roof top and the costs of storing that water in a customized man made underground ditch. A total of 36 soil and 20 water samples were collected using random sampling design from irrigated farms located in Kitengela and Isinya Divisions of Kajiado County. The samples were carefully packaged and labeled and taken to the laboratory for analysis of the chemical properties. Three greenhouses were purposively selected in Isinya and Kitengela sites to set up rainwater harvesting experiment. Gutters and pipes were installed to collect rainwater which was being collected to a ditch from where daily water levels were measured. Daily rainfall data was also recorded using rain gauges set on the experiment site. All the data collected were analyzed using both descriptive and GENSTAT statistical analysis packages. Generally, 8 water samples (40%) from both pans and boreholes were non saline, 9 samples (45%) were moderately saline and only 3 samples (15%) were severely saline. On the basis of SAR 10 water samples (50%) had low SAR while 7 samples (35%) had moderate SAR and 3 samples (15%) had a high SAR. On the basis of the combination of SAR and EC_w 10 samples (50%) were suitable while 10 samples (50%) were unsuitable. On the basis of Chloride toxicity 14 samples (70%) were suitable for surface irrigation, 5 samples (25%) moderately suitable while one sample (5%) was found to be unsuitable for surface irrigation. On the basis of sodium toxicity 9 water samples (45%) were suitable for irrigation while 8 samples (40%) showed moderate tendencies towards sodium toxicity. The rest 3 samples (15%) were toxic and unsuitable for irrigation. On the basis of bicarbonate toxicity only one water sample (5%) was suitable and it was sourced from a dam. Two samples (10%) were moderate and were also sourced from dams. The rest 17 (85%)

were found toxic and unsuitable for irrigation. In evaluating the effects of irrigation water on soil chemical properties, the results from the ANOVA indicate that the changes in soil pH EC toxic elements as a result of irrigation was not significant after irrigating with borehole and dam water but indicated significant changes for sodium and its SAR value from irrigation with borehole and dam water. The results for rainwater harvesting found that from a typical greenhouse rooftop that it is possible to harvest an average of 0.00075m^3 of water when it rained 1mm of rainfall falling on 1m^2 of Greenhouse rooftop. These results demonstrated a positive correlation between daily amount of rain harvested and daily rainfall measurements. It also found that it costs Kenya shillings 4850 to store same amount of water in a plastic tank compared to Kenya shillings 972.85 using a dugout ditch. The study concluded that water from boreholes and dams were both found to be suitable while others were unsuitable and that Isinya region faces sodium hazards in the any irrigation scheme. Rainwater harvesting also offers a viable option in addressing water scarcity in the region. In view of this it is recommended that for sustainable smallholder irrigation, farmers carry out preliminary study of the proposed irrigation water and the soils of the proposed farm in order for them to design a sustainable irrigation management system. The farmers will be able to anticipate changes as a result of irrigation and take corrective measures to ensure sustainability. It was also recommended that farmers explore the option of rainwater harvesting from greenhouse tops as a viable venture combined with storing the harvested water in a customized dug out ditch.

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ACRONYMS AND ABBREVIATIONS:

ASALs	Arid and Semi-Arid Lands
ALDEV	African Land Development Unit
EC	Electrical Conductivity
DRWH	Domestic Rain Water Harvesting
DDP	District Development Plan
FAO	Food and Agriculture Organization
GOK	Government of Kenya
GPS	Global Positioning System
IWMI	International Water Management Institute
IPCC	Inter-governmental Panel on Climate Change
KRWA	Kenya Rain Water Association
NEMA	National Environmental Management Authority
RHSIT	Rain Harvesting and Supplementary Irrigation Technology
SAR	Sodium Adsorption Rate
WB	World Bank
WQI	Water Quality Index

CHAPTER ONE: INTRODUCTION

1.1.Background Information

World population has been growing exponentially since the early 20th century. It is currently estimated that it is growing at 1.1 percent annually. In developing regions such as sub-Saharan Africa, population is growing at a higher rate of 3 percent (World Bank, 2001). Increasing human population translates to increasing demands for food. Food insecurity therefore is one of the major global problems. To overcome this problem, alternative strategies and options to increase food production, ensure maximum utilization of limited land, and use of appropriate technologies need to be considered. One option includes that of opening up more land for crop production through irrigation in the arid and semi-arid lands (Adhan, 2009; Ndegwa and Kiiru, 2011). Irrigation technology allows for whole year round production of food even in rain scarce lands such as arid and semi-arid lands.

Kenya is a water scarce country (GOK, 2005). Water demand exceeds renewable freshwater sources, and therefore in order for Kenya to realize food security, it needs to invest in alternative water technologies. Irrigation development in Kenya has a long history spanning more than 400 years. Records show that irrigation has been practiced for many years along the lower River Tana and in Elgeyo, Marakwet, West Pokot and Baringo regions (FAO, 2005). The colonial government had a huge set of irrigation proposals, but was constrained by social and political challenges of the time. The Mau Mau upheaval in 1946 led to the development of the African Land Development Unit (ALDEV) that identified irrigation as part of a broad agricultural rehabilitation program. It initiated a number of irrigation schemes namely; Mwea, Hola, Perkerra, Ishiara and Yatta using cheap labour from Mau Mau detainees (Adams and Anderson, 1988). The irrigation potential of Kenya has been estimated at 353,060 hectares and is distributed as follows; 180,000 hectares in the Lake Victoria basin; 52,500 hectares in the Rift Valley basin and 111,100 hectares in the East Coast basin which includes the Tana and Athi basins (FAO, 2005). Today irrigation in Kenya is under the management of the National Irrigation Board (NIB) established in 1966 by an Act of Parliament Cap 347.

Irrigation has been defined by Adams and Anderson (1988) to encompass certain basic principles namely; "the application of water to crops, the use of any technology, the removal of irrigation water through drainage; the management of water by crop selection such as crop water requirement, tolerance, cropping patterns and environmental conditions". Ayers and Westcot (1994) argue that, the application of water to crops is the primary activity and therefore successful irrigation requires both qualitative and quantitative aspects. According to Islam and Shamzad (2009) water quality issues had not been a major concern before because plenty of quality water was available, but the situation is now changing due to increasing demand for water by the growing population. Existing quality water is being depleted by an ever increasing population. This means alternative water sources must be considered alongside sustainable use of available water. A study done by International Water Management Institute (IWMI) by Seckler *et al.,* (1999) estimated that nearly 1.4 billion people, amounting to a quarter of the world's population, or a third of the population in developing countries, live in regions that will experience severe water scarcity within the first quarter of the 21st century. It further argued that slightly more than one billion people live in arid regions that will face absolute water scarcity by 2025. The situation could be worse given the recent changes in climate that has seen previously stable environments experiencing prolonged periods of drought.

Increasing population has also forced people to move from high potential areas to previously unoccupied lands such as the arid and semi-arid lands such as Isinya in Kajiado County that now boasts a number of private and commercial irrigation schemes that use borehole water (Thuo *et al.*, 2001). The quality of borehole water in terms of dissolved salts has been in doubt as to its capacity for sustainable agricultural production. Also, the rate of evaporation in the ASALs is high affecting the sustainability of water harvested stored in water pans.

Rainwater harvesting for irrigation is a technically and economically viable alternative to the use of poor quality borehole water. According to Barron (2008) it has been successfully done in Australia, Spain and China. In Kenya therefore, any significant irrigation development must include rain water harvesting, storage and the use of efficient irrigation technologies. This was the message given by a study commissioned by FAO (2013) to assess the opportunities and threats of irrigation development in Kenya's dry lands. According to Akintola and Sangodoyin (2011), rain water is the safest of all water sources but may be easily contaminated. Therefore well harvested rain water can provide alternative solutions to borehole saline water for sustainable irrigation systems.

Historically, the residents of Isinya Sub County have been semi-nomadic pastoralists Maasai. Land was communally owned. In the recent past, this lifestyle has changed due to changes in land ownership policies such as the on-going land adjudication and sub-division of group ranches leading to individual land tenure system. These have opened up more of the county to other ethnic groups other than the Maasai. As a result there has been increasing influx of immigrants into the area (Thuo *et al.,* 2001). The most important changes due to land adjudication have been the loss of communal land ownership, loss of traditional mobility and flexibility characteristic of pastoralism (GOK, 2013). Land use change from pastrolism to cultivation, is carried out mainly by immigrants. In recent years the Maasai are also taking up farming more seriously than in the past.

According to a study carried out by Odeny (2012) for Kipeto Energy Ltd, the commercial agricultural production system in Isinya is practiced on about 1.5% of total farmed land and is mainly for horticulture. The horticultural farming in the area between Kitengela and Isinya is becoming prominent and a major source of income and employment. Drip irrigation and green house technology is also gaining popularity among small scale farmers who have sunk boreholes in the region (Odeny, 2012).

The settlement pattern in Kajiado County has been influenced by the proximity to Nairobi City, high agricultural potential areas and mining areas. In Isinya Sub County, its proximity to Nairobi has attracted high immigration to Kitengela and Isinya regions, thus exposing them to high population growth (Thuo *et al.*, 2001).

This study therefore aims to establish the quality of borehole water used for irrigation and to assess the effect of such borehole water on soil quality. The study also aims to assess the cost benefit of harvesting and storing rain water for purposes of irrigation as an alternative to saline dry land underground water sources.

1.2. Statement of the Problem

Kenya is predominantly an agriculture-based economy. The success in Agriculture relies among other things the availability of adequate amounts of good quality water (World Bank, 2005). In order for Kenya to revolutionize agriculture, she needs among other things to address the problem of access to adequate quality water for food production. However, Kenya relies heavily on rain fed agriculture and yet about 80% of its land mass is classified as arid and semi-arid (Ngigi *et al.,* 2001; GOK, 2002). Therefore agricultural revolution will take place with the investment in technology that will turn Kenya's dry lands into food baskets. Such a revolution is only possible with irrigation technology.

Increasing population has also resulted in migration into dry lands around the urban centers in Kenya (Thuo *et al.,* 2001). According to Thuo *et al.,* (2001) the Nairobi peri-urban has experienced an increasing influx of the population who adopt irrigation and green house technology to ensure food production. This is the story in Isinya Sub County which is located in the dry lands of Kenya. In the past it was occupied by nomadic pastoralists who moved from place to place in search of water and pasture for their livestock (Bekurre *et al.,* 1991and Mngoli 2014). The government in an effort to restrain the nomadic life, introduced rain water harvesting by use of water pans for their livestock (Rutten, 2005). Water pans are now common in Isinya Sub County. Some of the pastoralists have adopted crop production and use the water in the pans and dams to irrigate their crops.

In the last decade, the population in the region has more than doubled (GOK, 2002). The migrant population is non pastoralist and engages in irrigation and green house technology to turn previously unproductive land into major suppliers of food to the city of Nairobi (Thuo *et al.,* 2001). To ensure regular supply of water for irrigation, the migrants have drilled many boreholes in the region. However, according to Kassas (1976), one of the challenges in irrigated agriculture in arid and semi-arid land is salinity. The reasons given are low rainfall received annually coupled with high temperatures that lead to high evapo-transpiration rate.

The migrant farmers who extensively irrigate their crops with underground borehole and water from dams face the risk of soil degradation unless the quality of the water are quantified so that farmers can employ appropriate management practices (Thuo *et al.,*2001).

In the event that salinity problem is confirmed as existing in the study area, then alternative sources of water need to be considered. The interest in rainwater harvesting is also related to the concerns of possibility of over abstraction of groundwater and the huge costs associated with drilling of underground water (Ngigi *et al.,* 2003).Rain water harvesting provides a viable and affordable option in the face of climate change.

In the recent past, the Kenya print media has reported that the Ministry of Agriculture and water officials have received reports from the farmers that their previously productive land has shown decreasing levels of production in proceeding years despite regular irrigation. However there are no published studies to support this allegation. This study therefore is an attempt to analyze the quality of the borehole water, including the water in water pans and to assess their effects on soil quality. The study also aims to assess the economic viability of harvesting rain water so that it may provide alternative solution to saline water in water pans and boreholes.

1.3.Justification of the Study

The Kenya National Development Plan of 2002–2008 recognizes Kenya as a water scarce country. Water demand exceeds renewable freshwater sources. To support the rapidly increasing population, and ensure the country's economic growth, there is need to optimize productivity of the dwindling landholding of high to medium potential lands and to open new lands in the ASAL areas by employing irrigation technology (Adhan, 2009; Ndegwa and Kiiru, 2011). Gichuki (2002) notes that, growth in population, increased economic activity and improved standards of living has led to increasing demand for freshwater resources in semi-arid regions of Kenya.

Kenya has been classified as a water scarce country because it does not receive adequate rainfall throughout the year for optimal agricultural production. Thuo *et al.,* (2001) and Ngigi *et al.,* (2001) noted that 80% of land in Kenya is found in the arid and semi-arid regions that receive less than 700mm annual rainfall. This therefore means that the country need to invest in other water sources to ensure optimal agricultural production and expansion into the ASAL regions. According to Thuo *et al.*, (2001) it is the migration into ASAL regions that has seen the adaptation of private irrigation schemes along the Nairobi city peri urban areas as it is in Isinya Sub County.

Irrigation water needs not only to be adequate but also of appropriate quality for the identified agricultural production. Ayers and Westcot (1994) and Blank *et al.*, (2002) noted that the problem of water used for irrigation relate to that of quantity and quality. Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. According to Hopkins *et al., (*2003) the effects of irrigation water on soils and plants depend on the water itself, the crop and the environment. Ayers and Westcot (1994) and Grattan (2002) pointed out that the suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use (Ayers and Westcot 1994). Water quality related problems in irrigated agriculture include among others salinity, toxicity and infiltration rate (Ayers and Westcot, 1994; Nakayama and Bucks, 1991). Bauders *et al.,* (2011) further continues to outline typical irrigation water quality concerns that deserve consideration that include the salt content, the sodium concentration, the presence and abundance of macro- and micro-nutrients and trace elements, the alkalinity, acidity, and hardness of the water.

According to Williams (1999) the problem of irrigation water quality is most common in arid and semi-arid lands. He further noted that the amount of salt found in irrigation water generally is greater in arid and semi-arid areas than in humid and sub-humid areas. This is because ASAL region experience high evapo-transpiration and poor drainage. In response to climate change and the need to adapt to these changes, and ensure food security for the growing population, the people are migrating to semi-arid regions and adapting irrigation to supplement rain fed agriculture and ensure all year round production of food crops (Ngigi *et al.,* 2001; Thuo *et al.,* 2001). Isinya Sub County is located in the semi-arid region of Kenya and influx of population into the area has seen an increase in the use of irrigation for agricultural production. The migrant population is using borehole water and water from pans for irrigation (Thuo *et al.,* 2001). As outlined above there is high possibility of underground water in ASALS containing appreciably high amounts of salts. This is a possibility in Isinya because the quality of the water remains unknown. Therefore, there is need to assess the quality of that water, evaluate the effect on soil quality in order to ensure sustainability in the established irrigation systems. The challenges faced in the drylands on the availability of adequate sources of quality water for crop production also demands that alternative sources such as rain water need to be explored in terms of possible quantities that can be harvested and the cost of harvesting and storage.

1.4. Study Objectives

1.4.1. Broad Objective

To contribute towards promoting sustainability of dry land irrigation agriculture in Isinya Sub County

1.4.2. Specific Objectives

i. To assess quality and suitability of water for irrigation in Isinya Sub County.

ii. To assess the effect of the irrigation water on the soil chemical properties.

iii. To determine the amount of rainwater that can be harvested from a typical greenhouse roof top.

1.5. Hypotheses

i. All irrigation water sources in Isinya Sub County are not suitable for irrigated agriculture

ii. Irrigation water in Isinya Sub County does not affects soil chemical properties

iii. It is not viable to harvest adequate amount of rain water from a typical greenhouse rooftop

iv. It is not cost effective to store the harvested water in a ditch than in a plastic tank

CHAPTER TWO: LITERATURE REVIEW

2.1. Quality of Irrigation Water

Sustainable irrigated agriculture depends on availability of adequate and good quality water. Ayers and Westcot (1994) defined water quality as the characteristics of a water supply that will influence its suitability for a specific use. It is defined by certain physical, chemical and biological characteristics. Irrigation water quality therefore refers to its suitability for use in irrigated agricultural production. Good quality water has the potential to allow maximum yield under good soil and water maintenance practices. Knowledge on irrigation water quality is therefore critical to the understanding of management for long-term agricultural productivity.

The key qualities of irrigation water that have been considered to affect its suitability consist of the salinity, the relative sodium concentration, the alkalinity and acidity, and the toxic elements (Ayers and Westcot 1994). Bauders *et al.,* (2002) defined salinity as the amount of dissolved salts in water. All water used for irrigation contains some level of salts that comes from the weathering of parent material (Grattan, 2002). According to Bauders *et al.,* (2002) salinity problems in irrigation water affects the availability of water to the crop by creating osmotic effect where the crop is unable to compete with the salt ions for water. Salinity in irrigation water is measured by Electrical Conductivity (EC_w). Ayers and Westcot (1994) further indicates that a given water is said to have salinity problems if its ECw is above 3dS/m. According to Bauders *et al.,* (2002) EC_w measures salinity from all the ions dissolved in a water sample and includes both negatively charged ions such as chlorides (Cl^{-}), nitrates ($NO^{-}3$) and positively charged ions such as calcium (Ca++), sodium (Na+).

Hussain (2010) explained that infiltration problems are indicated when sodium content in irrigation water is high to the extent that it increases the exchangeable sodium in the soil exchange complex and so disperses the soil more rapidly with the result that soil particles seal the soil macrospores. The result is that the ability of the soil to absorb water is reduced, therefore water availability to the crop is also reduced. Infiltration problems in irrigation water is measured sodium content in the water relative to calcium and magnesium. It is given by Sodium Adsorption Rate (SAR). Ayers and Wescot (1994) also shows that chloride toxicity in irrigation water occurs when the chloride content is in such levels that when they are taken up by crops, are transpirated and accumulated in the leaves to levels that exceeds the crops capacity to tolerate, and so cause injury to the leaves of the crop. Toxicity limits differ from one crop to another.

Williams (1999) noted that the amount of salt found in irrigation water generally is greater in arid and semi-arid areas than in humid and sub-humid areas due to high evapo-transpiration rate and low amounts of rainfall in these climatic conditions. Salinity problem exists if salt accumulates in the crop root zone to a concentration that causes a loss in yield. Salts accumulate in the soil with each irrigation cycle (Grattan 2002). The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management and the adequacy of drainage (Malano and Burton 2001; Pereira *et al.,* 2002). Grattan (2002) pointed out that if salts become excessive in the soils, losses in crop yield will result because too much salt in the soil-water increases the force the plant must exert to extract water and in the process causes a water shortage similar to that of a drought. To prevent yield loss, salts in the soil must be controlled at a concentration below EC_w 3dS/m.

As indicated by the National Development Plan GOK (2002), Kenya is a water scarce country that needs to explore other sources of water for agricultural development in order to feed the ever increasing population. Kenya's over 80% drylands is underutilized and this could be put to use by adopting irrigation technology.

According to Grattan, (1999) borehole and well water in the dry lands have been known to be saline. Omran (2012) carried out a study to assess and map suitability of well water used for irrigation in Egypt. He discovered that most of the samples taken from wells fell into the unsuitable water quality index category. A similar study was done by Ndegwa and Kiiru (2010) in Turkana district to assess the quality of soil and water used under irrigation in the regions. Soil samples were collected from both irrigated and non-irrigated areas and analyzed. The study discovered that non irrigated fields were not saline on shallow depths but salinity increased with depth from 20m. However irrigated fields demonstrated strong salinity on soil surface but salinity decreased with depth.

Nata *et al.,* (2009) carried out a study in Debre Kidane watershed in Ethiopia to assess groundwater suitability for irrigation purpose. Based on the guidelines for irrigation water quality, results indicated the groundwater is suitable for irrigation with some minor exceptions whereby during the rainy season, 89% of the samples were in the water class "good" and 11% "permissible" whereas during the irrigation season only 30% are classified as "good" and 70% under "permissible" class as per the calculation of Irrigation Water Quality Index as provided by Hussain *et al.,* (2014).

The quality of groundwater has been believed to vary between seasons such as long, short rains and, dry season in tropical countries. In temperate regions water quality is also affected by changes in seasons such as summer, winter, spring or autumn. For example Joshi *et al.*, (2009) assessed the quality of waters from the river Ganga in India and their variability in seasons of winter, summer and the rainy season. Water quality variables were measured in the river over a period of two years and the results indicates that river water in rainy season is not suitable for irrigation purpose because of high values of total dissolved salts, EC_w and Exchangeable Sodium Percentage (ESP), but were found to be suitable in the other two seasons. Similarly Ruhakana (2012) conducted a thesis research study to assess spatial and temporal water quality variability and its response on growth of irrigated rice in Rusurirwamuyinga sub-catchment in Rwanda by considering among others seasonal variation (dry season, moderate and rainy season) in order to find out the variation of irrigation water quality within time and space. The results showed significant variation of irrigation water quality both in season and in stream positions

The above literature indicates mixed results on the quality of groundwater for irrigation. In view of the increasing migration into Isinya Sub County coupled with increased intensive irrigated agriculture from the region, there is an urgent need to carry out research to evaluate the quality of the water used for irrigation in these regions, assess their effects on soil quality and propose alternatives interventions in the event that the water quality is not suitable.

2.2.Effects of Irrigation Water on Soil Chemical Properties

Soil quality is one of the most important factors required when developing sustainable agricultural practices. Wang and Gong, (1998) defined soil quality as the capacity of the soil to meet plant growth requirements. It is not possible to measure soil quality function directly but scientists use soil quality indicators to evaluate how well soil functions (Carter *et al.*, 1997). There are three main categories of soil quality indicators: chemical, physical and biological indicators. Chemical indicators include nutrient cycling, water relation and buffering characteristics. Physical indicators include aggregate stability and soil water relations. Biological indicators include biodiversity, nutrient cycling and filtering. Some indicators are descriptive while others must be measured using laboratory analyses.

In order to assess soil quality Smith and Doran, (1996) proposed that measurements of pH and Electrical Conductivity provide valuable measures to assess the soil condition for plant growth, nutrient cycling and biological activity. Other measures include soil nitrates, aggregate stability, and water holding capacity, bulk density and total organic carbon among others.

Ayers and Wescot (1994) argues that a major concern in irrigation agriculture is that irrigation and drainage systems generate problems that make them unsustainable. Some of these problems include salinisation, alkalization, water logging and acidification. The accumulation of salts in soils can lead to irreversible damage to soil structure essential for irrigation and crop production. Effects are most extreme in clay soils where the presence of sodium can cause soil structural collapse. This makes growing conditions poor, soils very difficult to work and prevents reclamation by leaching using standard techniques.

Since irrigation water contains some level of a mixture of naturally occurring salts, irrigation over time results in accumulation of salts in the soil (Rhoades, 1996). The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management and the adequacy of drainage (Grattan, 2002).

A review of previous studies indicated that several studies on the effects of irrigation on soil chemical properties. Some studies focused on highlighting the difference in the soil chemical parameters before and after irrigation, while others compared parameters between irrigated and non-irrigated fields. Still others simply measured the actual change in the parameters while others carried out statistical analysis to measure significance in these changes.

For example, Cucci *et al.,* (2013) carried out a two-year research at the University of Bai in Italy, to study the effects of irrigation using saline and sodic water on soil physical and chemical properties. Their research did not show any significant effect of irrigation water salinity and sodicity, when used with leaching but showed significant effect when water with 0.1 M salt concentration was used. Bendra *et al.,* (2012) in a field survey in North Africa to assess soil quality, focusing on the soil physico-chemical properties, found positive correlation between irrigation and soil quality but the research also indicated that research studies relating to the effect of irrigation on soil resources in Northern Africa are often poorly documented. José Luis Costa (1999) did a similar study in Buenos Aires Province of Argentina with similar results.

Research to assess effects of saline water on agricultural production aspects such as soil quality and crop yield has been carried out by Rietz and Hayness, (2003) who studied the effects of irrigation-induced salinity and sodicity on the size and activity of the soil microbial biomass in vertic soils on a Zimbabwean sugar estate. The results indicated that increasing salinity and sodicity resulted in a progressively smaller, more stressed microbial community which was less metabolically efficient. Small increases in salinity had highly detrimental effect on the microbial community. They concluded that agriculture-induced salinity and sodicity not only influences the chemical and physical characteristics of soils but also greatly affects soil microbial and biochemical properties. Similarly, Thompson (1991) thesis research study in Montana University to determine if crop yields and soil properties were affected under sustained irrigation with water quality of increasing salinity and sodicity showed that long term irrigation and accelerated salt loading resulted in significant amounts of salt and sodium accumulation in all soils. All soils became saline or saline sodic when irrigated with water assumed to be representative of future irrigation water quality. In Italy, Tedeschi and Aquilla (2005) carried out an irrigation experiment with saline water at different concentrations over a 7-year period on the same clay–silty soil in the Volturno Valley at Vitulazio, Italy to evaluate long-term effects of irrigation with saline water on crops and soil. The results indicated that irrigation with saline water led to an increase in Exchangeable Sodium Percentage (ESP) and a degradation of the soil physical properties that was estimated indirectly by measuring aggregate stability in water.

In Kenya a lot of similar studies on the effects of irrigation water on soil quality have been done especially by graduate students of agriculture. Tum (1996) did a thesis study to determine the causes of secondary salinization in Kibwezi district which established that irrigation was significantly responsible for changes in certain chemical properties of soil. Other studies in Kenya include that of Ndegwa and Kiiru (2010) who investigated the effect of irrigation on water and soil quality in Turkana district and the results were that non irrigated fields indicated a non-saline soil surface with EC_s of 1.31 ds/m, which turned saline at depth of 0.20 m with EC_e of 5.57 ds/m while periodically irrigated fields were strongly saline on the soil surface with EC_e of 8.86 ds/m, but decreased to non-saline level of 3.41 ds/m at 0.40 m and intensively irrigated fields had low salinity with depth due to frequent leaching of salts.

The results of the above studies indicate that different sites have unique characteristics in terms of the effect of irrigation water on soil quality. This is one indication that in order to ensure sustainable agricultural productivity, each location needs its own assessment. Isinya Sub County have in the recent past experienced an influx of migrants who have embraced irrigated agriculture. These farmers need to carry out their on-site soil quality assessment before engaging in irrigation in order for them to design relevant soil and water management systems. This study therefore aims to shed more light and offer advice to farmers on possible management methods while using irrigation water from various sources including underground water.

2.3. Rain Water Harvesting and Costs of Customized Rainwater Storage

Rain water harvesting is the collective term used to indicate a wide variety of interventions that uses rainfall through collection and storage, either in soil or in man-made dams, tanks or containers to bridge dry spells and droughts. Chanan, (2007) defines rain water harvesting as the practice of collecting water from surfaces on which rain falls, and storage of this water for later use. The concept of water harvesting has a long history dating to over thousands of years. Kumar, (2000) indicates that the Indian people have practiced water harvesting for over 5000 years.

Rain water harvesting offers important benefits such as provision of good quality water for plant irrigation, reduced storm water runoff from land to cut down on soil erosion and pollution of rivers and springs (Ngigi, 2003; and Eruola *et al.,* 2010)). Rain water harvesting offers a great potential for water savings and an alternative water source during drought. However there are limitations and drawbacks to the adoption of rain harvesting by communities (Ngigi, 2003). For example, rain water harvesting is only practical in locations where rainwater can be collected in sufficient quantities during a rainy season. Adequate and proper systems for capturing and storing the rainwater must be put in place and maintained well. Sometimes this may be expensive especially for smallholder farmers. Other challenges associated with adoption include awareness, technical expertise and cost of installing such a technology. Li *et al.,* (2000) has proposed that more research and dissemination need to be done to facilitate effective and affordable rain water harvesting technologies to encourage the adoption by smallholder farmers.

Despite the benefit offered by rainwater harvesting, limited research has been done to evaluate the quantity of rainwater that can be harvested from different surfaces including rooftops such as greenhouse tops. However a number of studies have been done to explain the slow rate of adoption of rain water harvesting by farmers. Kubbinga, (2013) studied the potential of rain water harvesting in assisting smallholder farmers in Eastern province of Kenya. He established that costs were a major economic constraint, though the benefits to outweigh these and other social costs. His study highlighted the importance of further research on the technical, economic, environmental and social costs and benefits of rain water harvesting systems. Feng He, (2007) evaluated the determinants of farmers' decision of adoption of rainwater harvesting and supplementary irrigation technology (RHSIT) in the semiarid Loess Plateau of China. He found 12 factors that determine the farmer's decision to adopt the technology. Among these include access to finances and credit. Li *et al.,* (2000) also concurs with the above observation and recommends that to be successful rain water harvesting needs to be integrated in a comprehensive agricultural-management system by combining it with other agricultural technologies and management practices.

In the context of the present study, few studies have been done to evaluate possible quantity of rainwater that can be harvested from a rooftop. Studies done by Eruola *et al.,* (2010) undertook to assess the qualitative and quantitative aspects of harvesting rainwater from rooftops with different slopes. His findings were that there was a direct relationship between volume of water harvested and the slope of the rooftop. The steeper the slope the more the water harvested. The work of Patel *et al.,* (2014) in Sanlkalchand Patel College of Engineering (SPCE), Visnagar India found that 0.999 litres of water could be harvested from 1m^2 of surface rooftop when it rained 1mm of rainfall. Similarly Aladenola and Adeboye (2010) established that 0.800 litres of water could be harvested from 1m^2 of rooftop when it rained 1mm of rainfall.

The work of Kumar and Mandal, (2014) who set up a rain water harvesting system in a remote village in Bangladesh and harvested 0.261 litres of water from 1m^2 surface area raining 1mm of rainfall. Patil-Pawar and Mali (2013) who attempted to evaluate the potential for harvesting rain water from a roof top in a village in India, harvested 0.755 litres of rainwater from 1m^2 surface area when it rained 1mm rainfall.

Kahinda *et al.,* (2010) did a study to find a methodology that enables water managers to incorporate the climate change component during the design phase of domestic rain water harvesting (DRWH) systems. The Roof model was used to calculate the optimum size of the rainwater harvesting storage tank and appraise its water security which was found about 30%. On the basis of forecasted rainfall water security attained by a 0.5 m^3 rainwater harvesting tank was found between10–15% in the arid areas, 15–20% in both the semi-arid and dry sub humid areas and 30–40% in the humid zones.

Sharma *et al.,* (2009) carried out a study in a horticultural farm in Athi River outside Nairobi, Kenya to establish how much rainwater, runoff water and flood water could be harvested to meet the water deficit and overcome sodicity problems experienced by the farm. The study established that rainwater harvesting provided 60% of its annual irrigation water requirement of an average about 300,000 m^3 and that rainwater harvesting and its storage would be an effective solution for both commercial and subsistence farmers. Farreny *et al.*, (2011) did a correlation study between runoff and rainfall and found it to be highly correlated (Pearson coefficient > 0.95 and $p < 0.05$ for all roofs). The regression model (R ¼ mP þ n) between roof runoff (R) and precipitation height (P) for each roof was presented and all the regression parameters were statistically significant ($p < 0.05$).

Studies relating to the cost of storing Rainwater included that of Godfrey *et al.*, (2009) who undertook a Cost–benefit analysis for grey water reuse by considering internal and external costs and benefits. He concluded that internal and external benefits of grey water reuse are substantially higher than the internal and external costs. Ngigi (2005) carried out a hydro-economic analysis of rainwater harvesting systems in Kalalu and Matanya areas of Laikipia districts with the aim of analyzing some of the factors that affect their adoption by smallholder farmers. They were found to be an economically viable option for improving agricultural production and livelihoods of smallholder farmers in drought prone rural areas.

In Sri Lanka and Uganda a DFID funded research project was carried out by Martinson and Thomas, (2002) to facilitate the design of a low cost system to harvest rain water from rooftops among rural communities and the results of were used to guide the design of low cost rainwater storage facilities. The tarpaulin tank was given as an example of a successful low cost design that is being replicated in southern Uganda. In Bangladesh Islam *et al.*, (2014) carried out a research to investigate rainwater harvesting and storage as a low cost option compared to the portable water. The findings were that roof top rainwater harvesting was viable and affordable at $171 which was assumed to be affordable in the region.

In Bangladesh India, the Panscheel Cooperative Group housing Society, (Source: http://www.rainwaterharvesting.org/Urban/panchsheel.htm) set up the rainwater harvesting system on ther rooftops of their hou sing scheme were able to harvest 174,575m^3 of water at a total cost of Rs. 800,000.00. In another of their project, Mother Dairy F & V Unit located in the same region they collected a total of 322, 249.802m^3 of water from 89,370m^2 at a total cost of Rs. 435,000 equivalent of Rs. 1.35 per m^3. Babu (2010) set up a rain water harvesting project on the roof top to harvest safe drinking water in India and found the cost to be Rs. 1300 per 1m^3.

It can be observed from the above literature review that few studies relating to measuring and quantifying actual amounts of rainwater collected from rooftops has not been carried out exhaustibly in Kenya. Most of the studies done in Kenya on rainwater potential relied on the

Gould and Nissen Formula to evaluate potential of a given collection surface to collect specific amounts of rainfall. This study was carried out to assess the amount of rainwater that could be harvested from a typical greenhouse roof top and the costs of storing that water in a customized man-made underground ditch lined with a dam liner. The results will contribute to knowledge that could be used by smallholder farmers in water stressed agro-ecological zones.

CHAPTER THREE: MATERIALS AND METHODS

3.1.Description of the Study Area

The study was undertaken in Isinya Sub County in Kajiado County. Isinya Sub County comprises the Isinya and Kitengela Divisions and is located between longitude E37.12^{o} and E36.72^{o} and latitude S1.38^{o} and S1.81^{o} (KNBS, 2009). Generally the landscape falls between altitude 1760 and 2023 meters above sea level and covers an area of about 1,056.0 square kilometers (Figure 1).

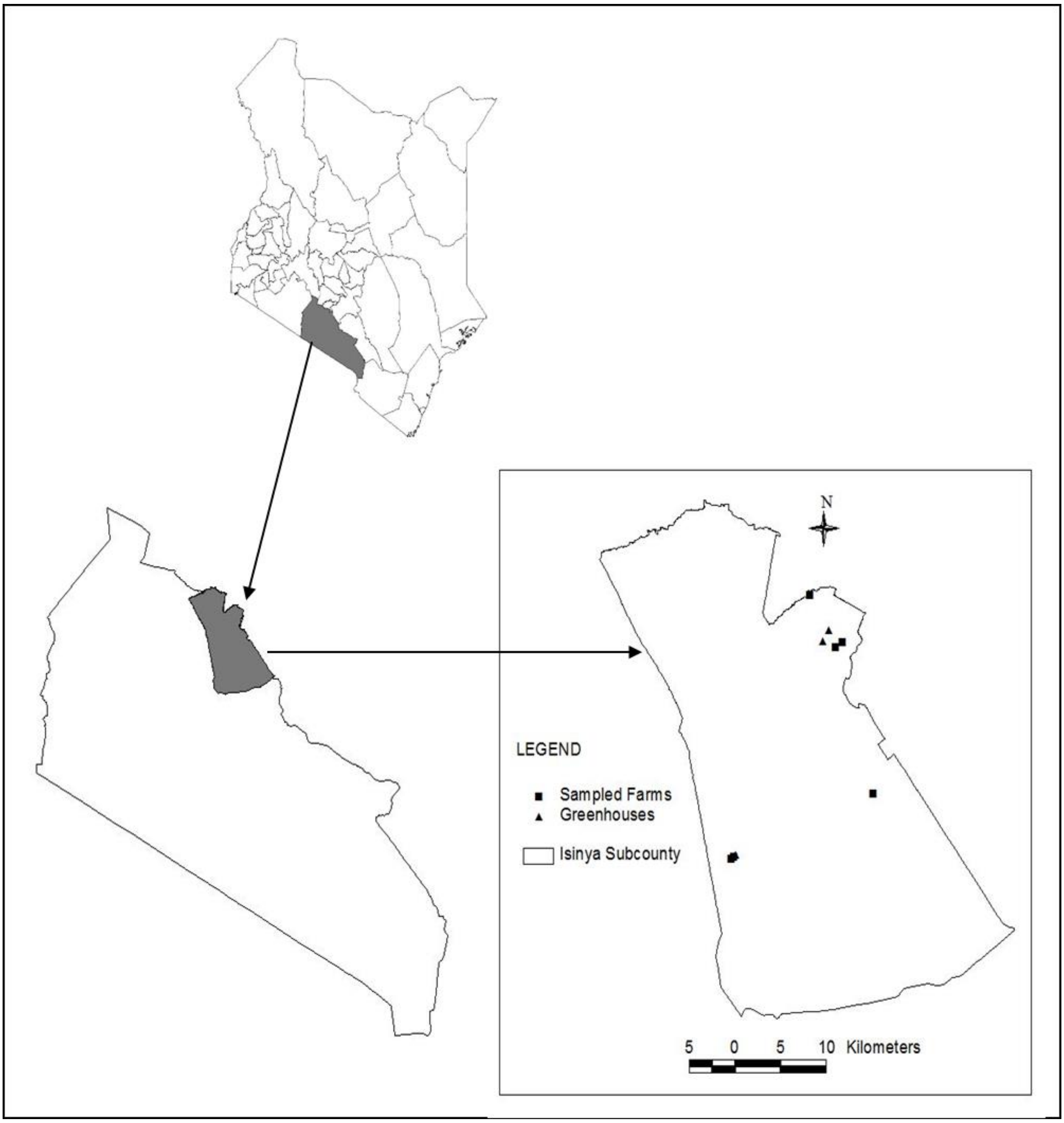


Figure 1: Map of Isinya Sub County, Kajiado County

Isinya Sub County was selected purposely because of its high population density and the fact that its regions lies within two eco-zones IV and V. Due to urbanization and increasing influx of the people to the northern region of Kajiado County, there is increasing small scale irrigation schemes in the area (Thuo *et al.,* 2001).

The County is located under four eco-zones of the Rift Valley, the upland Athi Kapiti Plains, the Central Hills, and the Amboseli Plains (Matheson, 1966). It rises from a low altitude of about 500 meters around Lake Magadi to about 2,500 meters in area around Ngong Hills. The study area in Isinya Sub County falls within the Athi Kapiti Plains characterized with open rolling land and lies generally between altitudes 1533 and1760 meters above sea level. The Plains drain towards the Athi River basin in the east (Figure 2). Geologically, they derive from volcanic soils but there is a band of tertiary sediments running south-west to north-east across the center of the plains. The soils vary from Ferralsols, Luvisols, Arenasols, Regosols, Leptosols, Lixisols, Cambisols and Vertisols (Matheson, 1966).

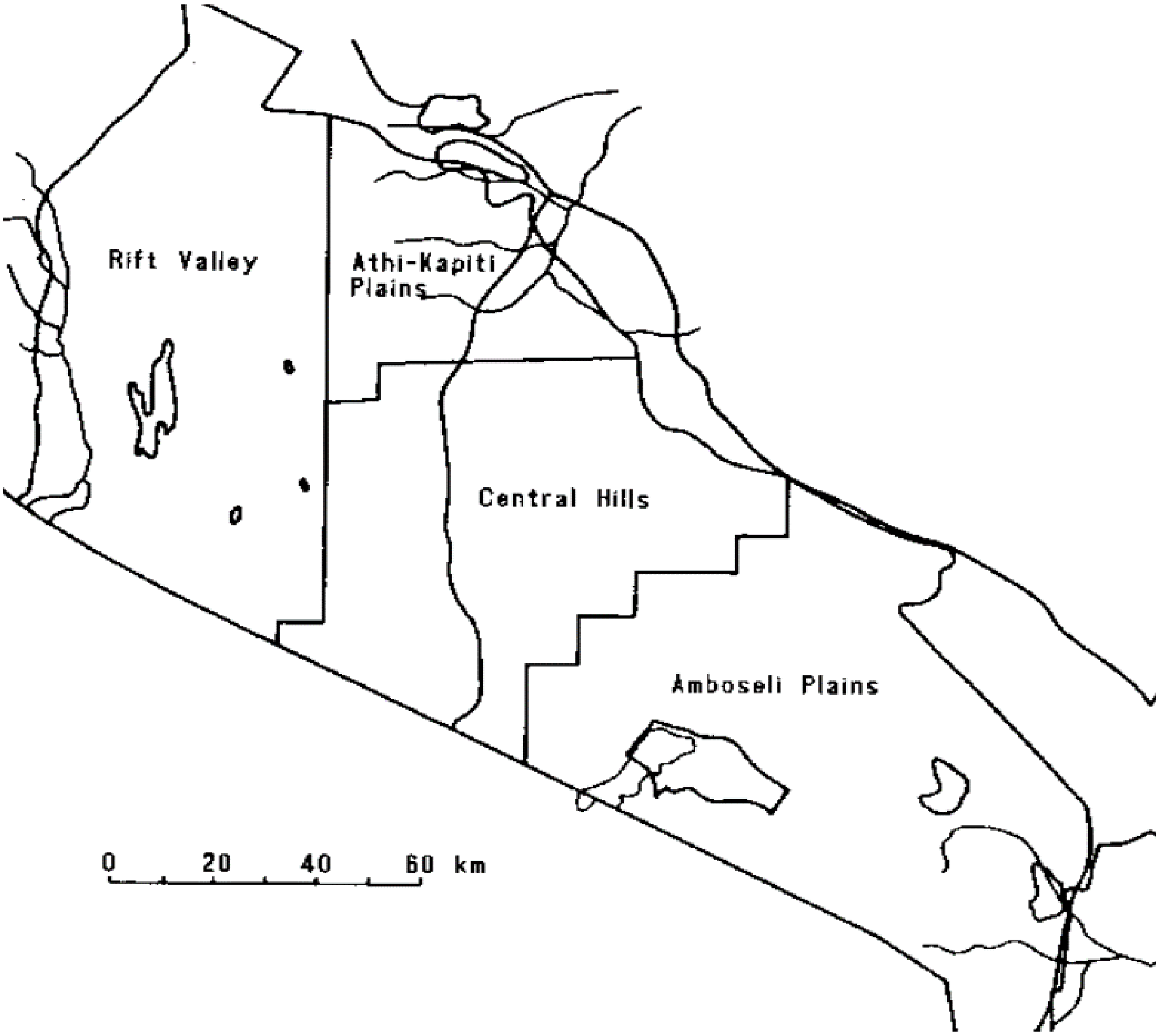


Figure 2: The Eco zones of Kajiado County. Source: FAO Publications 1991

The soil parent material in the area are classified into four broad classes namely the quaternary basement rock soils, tertiary volcanic rocks, pleio-cene volcanic rocks and superficial deposits (Matheson, 1966). Isinya sub County being located at the beginning of the Rift Valley and the beginning of Athi Kapiti Plains has soils that comprise mainly the Basement system rocks such as crystalline limestone which has a lot of carbonate, quartzite which contains primarily silica (Silicon dioxide), gneiss which is a highly metamorphosed quartz and granites which is a hard igneous rock mainly composed of four minerals such as quartz, alkali feldspar, plagioclase feldspar, and hornblend. The Ferralsols, Luvisols, Arenasols, Regosols, Leptosols, Lixisols, Cambisols and Vertisols are found in the low-lying areas towards the Central hills. The soils are of medium to poor agricultural productivity depending on location (Sombroek *et al.*, 1982).

The main vegetation in the district comprise the wooded grassland, open grassland, wooded bush land, bushed grassland and forest. Woody species include; *Acacia tortilis, Acacia xanthopholea, Acacia mellifera, Commifora schemperi, Balnites aegyptiaca, Balanites gabra, and Salvadora persica*. Grasses include; *Pennisetum mezianum, Pennisetum stramineum, Chroris roxburghiana* and *sporobulus angustifolia, Chloris guyana* and *Cenchrus ciliaris* (Solomon *et al.*, 1991).

Most of the Kajiado County lies in the semi-arid and arid ecological zones IV to VI. Isinya Sub County in the Athi kapiti plains lies on agro climatic zone V. The maximum temperatures are 34 degrees Celsius around Lake Magadi to a mean minimum of 10 degrees Celsius on the foothills of Mount Kilimanjaro and Ngong Hills. Isinya Sub County generally experiences high temperature averages near the county maximum of 34 degree Celsius. The annual rainfall received range from 500 mm around Amboseli and Lake Magadi to 1250 mm on the slopes of Mount Kilimanjaro. The region experiences bimodal rainfall with the short rains occurring between October, November, December, and the long rains occurring between March, April and May of each year (District Development Plan, 2008-2012).

Kajiado County has few permanent rivers whose source is the Ngong hills water catchment. These rives comprise the upper Athi River, Embakasi, Kitengela, Stony Athi and Kiboko River with its tributaries, Olkejuado and Selenkei. The County therefore depends on ground water reserves whose availability is mainly influenced by climate and topography as well as origin of underlying parent rock. The other alternative source of water for domestic and livestock include water pans, dams and shallow wells (District Development Plan, 2008-2012; NEMA, 2009).

Thus, the region relies heavily on several small dams and boreholes. At least 290 boreholes were drilled between 1938 and 1982, 43 percent of them between 1970 and 1982 (Dietz *et al.,* 1986). In the Athi-Kapiti area, most boreholes are clustered at the northern end due to increasing settlements in the area. The most important single structure for the provision of water in the County is the pipeline that passes from the Kilimanjaro foothills to Kitengela through Sultan Hamud along the Nairobi-Mombasa road (Solomon *et al.,* 1991). Most of dams constructed have silted up, broken up or washed away over time (Dietz *et al*., 1986).

3.2.Experimental Design and Treatments

3.2.1. Selection of farmers

Participatory Geo Information System (PGIS) was used to map water sources from which a total of 20 farmers with irrigated farms were purposively selected in the study area. Ten of these farmers irrigated their farms using water from boreholes, while the other ten irrigated their farms with water from water pans. Data on irrigation water were collected from these 20 farmers while data on soil were collected from six of these 20 farmers. In addition a rain water harvesting system was set up in three farms that had constructed green houses on their farms.

3.2.2. Installation of greenhouse rooftop harvested rainwater

The rainwater harvesting experiment was set up in three farms that had installed green houses. The greenhouse rooftops was the collection surface and they had rectangular shapes. Rainwater was collected from the greenhouse tops using gutters established on the sides of the green house and directed to ditches with a maximum of $16m^3$ of water. Each green house had different surface areas.

3.2.3. Data Collection

3.2.3.1.Measurement of greenhouse rooftop harvested rainwater

The greenhouse rooftops had a rectangular shape. Therefore, to calculate the size of the selected greenhouse roof top, the following formula was used;

Source: https://www.conklin.com/files/pdf/rs0825_011_1211_QuonsetRoofCalculation.pdf

Roof surface = ½(Diameter x π) * Length; ………………………..Equation 1

Where; π (Pi) is estimated at 3.142

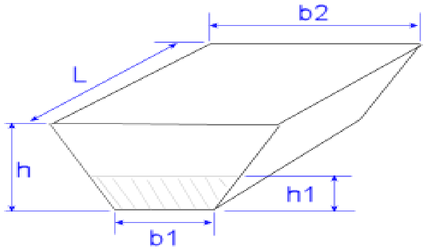
The total surface area for each greenhouse rooftop were as given on Table 1 below:

Table 1: Green House Rooftop Measurements and Surface Area

Green House	GPS Location	Surface area	Total surface area
1 (Kitengela)	**S01.49002° E036.94198°**	(4m x 3.142)* 15m	**=188.52m²**
2 (Kitengela)	**S01.49857° E036.93623°**	(4m x 3.142) * 43m	**=540.424m²**
3 (Isinya)	**S01.67727° E036.85070°**	(4m x 3.142) * 15m	**=188.52m²**

The rainwater was collected to a dug out ditch and daily water level readings in the ditch were done daily at 9 am from one point using a long straight wooden stick and measurements recorded in meters and centimeters. One rain gauge was installed in each of the three sites next to the greenhouse. Rain gauge readings were recorded after every rainy day in the following morning at 9 am.

The readings were done between April and December 2013 and the total volume of rainwater harvested during this period was calculated as follows;



Volume = L * (b1 + (b2 - b1) * h1 / h + b1) * h1 / 2………Equation 2

Where L=4m, H=2m. b1=1m and b2=3m

Figure 4: Ditch shape and Dimensions

To derive the formula for the collection ditch the following calculations were undertaken:

TanØ= x/h=1/2(b2-b1)/h.

Therefore the Cross Sectional Area= ½(b1+2x+b1)*h...............(a) Equation 3

But TanØ= x/h=1/2(b2-b1)/h.

Therefore solving for x in the above equation:

X=h1*1/2(b2-b1)/h...(b) Equation 4

Substituting in Equation (a) above:

CSA=1/2{b1+ [h1*1/2(b2-b1)]/h+b1}*h1

The Volume for Water collected in the above ditch is given as:
Volume= 1/2{b1+ [h1*1/2(b2 b1)]/h+b1}*h1*L....................(c)…………Equation 5

3.2.3.2.Water Sampling and Analysis

Water samples were collected during pre-arranged visits to their farms from both boreholes and water pans. The samples were collected starting from the rainy season beginning in April the dry season up to the end of September 2013 from the 20 farmers.

The collected water samples were carefully kept in clean clearly labeled plastic containers and tightly capped and taken to the laboratory for chemical analysis for evaluating the suitability of irrigation water.

The 20 water samples collected from boreholes and dams was evaluated in the laboratory by following the Ayers and Wescot, (1994) guidelines on irrigation water quality for the following quality characteristics: pH, Electrical Conductivity, mS/cm, Sodium, me/litre, Potassium, me/litre, Calcium, me/litre, Magnesium, me/litre, Carbonates, me/litre, Bicarbonates, me/litre, Chlorides, me/litre, Sulphates, me/litre and Sodium Absorption Ratio (SAR).

The data obtained from the water chemical analysis were compared with the guidelines on assessment of irrigation water as given by Ayers and Westcot, (1994) as shown on the Table 2 below and analyzed accordingly.

Table 2: Guidelines for the interpretation of irrigation water quality

Water quality parameters			**Units**	**Degree of Restriction on Use**		
				None	**Slight to Moderate**	**Severe**
	EC_w		dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS		mg/l	< 450	450 – 2000	> 2000
SAR	= 0 – 3	**and EC_w**		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6			> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12			> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20			> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40			> 5.0	5.0 – 2.9	< 2.9
	Sodium (Na)[4]		me/l			
	surface irrigation			< 3	3 – 9	> 9
	sprinkler irrigation			< 3	> 3	
	Chloride (Cl)[4]		me/l			
	surface irrigation			< 4	4 – 10	> 10
	sprinkler irrigation			< 3	> 3	
	Boron (B)[5]		mg/l	< 0.7	0.7 – 3.0	> 3.0
	Nitrogen (NO_3 - N)[6]		mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)		me/l			
	(overhead sprinkling only)			< 1.5	1.5 – 8.5	> 8.5
	pH			**Normal Range 6.5 – 8.4**		

3.2.3.3. Soil sampling and analysis

In order to analyze for the effects of using irrigation water on soils, a Completely Randomized Design was employed to guide soil sampling. The soil samples were from experimental unit and the treatments which were borehole and water pans irrigation water were collected from six irrigated farms and from adjacent non-irrigated areas as controls. Three of these farmers use borehole water while the other three use water from water pans.

The samples were collected in 3 replicates for each treatment making a total of three soil samples from each farms. In total, 18 soil samples were collected from irrigated areas and another 18 samples from non-irrigated areas adjacent to each of the irrigated farms as controls. Therefore, a total of 36 soil samples were collected for laboratory analysis.

The samples were collected from the top layer, (0-30 cm) and packed in clean polythene bags and labeled appropriately before being transported to the laboratory. Once in the laboratory the samples were air-dried and sieved to 2mm diameter. The sieved fraction was then stored in plastic boxes at room temperature before analysis.

The 36 collected soil samples were analyzed in the laboratory using standard methods as done by Rhoades, (1996) for the following chemical characteristics: pH, Electrical Conductivity, mS/cm, Sodium, me/litre, Potassium, me/litre, Calcium, me/litre, Magnesium, me/litre, Carbonates, me/litre, Bicarbonates, me/litre, Chlorides, me/litre, Sulphates, me/litre and Sodium Absorption Ratio (SAR).

3.2.3.4. Cost of constructing rooftop rainwater harvesting and storage system

Appropriate materials were bought to set up a water collection, conveyance and storage systems.

Ditches were dug close to the green house in a trapezoid shape to prevent the side walls from collapsing. The measurement of the trapezoid was 4m in length, 3m top base and 1m bottom base and 2m height. Cost of materials for ditch construction was recorded.

The ditch was lined with a polythene dam liner and reinforced on the side with timber as shown in the Figure 3 below. The top of the ditch was covered with corrugated iron sheets to prevent evaporation and for security purposes. Rain water conveyance from green house top to the ditch was constructed and labor costs recorded.

Figure 3: Greenhouse Rooftop and collection ditch

All costs involved in the construction of the rain water harvesting system in each of the green houses was recorded and analyzed to arrive at the final cost for each green house. Costs of different brands of water storage tanks were assessed and a comparison was done between the cost of storing one liter of water using traditional storage systems of plastic tanks and the customized design of a dug out ditch covered with anti-seepage and anti-evaporation materials.

3.2.4. Statistical Data Analysis

3.2.4.1.Soil and Water

The 36 samples analysed in the laboratory were averaged according to water sources. The soil samples that were irrigated with dam water were averaged to get three replicates, while the soils that were irrigated with borehole water were averaged to get three replicates. The controls were also averaged in a similar manner to get three replicates. The total reading of 9 samples were analyzed using ANOVA in GENSTAT.

3.2.4.2.Volume and Costs of Rainwater Harvesting and Storage

Total volume of rain water collected and stored in the ditches was calculated for each greenhouse. The three greenhouses were considered as replicates to reduce errors and increase precision of data analysis. The average collected from the green houses was correlated with rain gauge reading to accept or reject the hypothesis that it is not viable to harvest adequate amount of rain water per one millimeter of rainfall.

Total costs of constructing and maintaining the rainwater harvesting and storage system was recorded. The cost prices for traditional water storage tanks for different brands were also collected.

A comparison was done between the cost of storing one liter of water using traditional storage systems of plastic tanks and the customized design of a dug out ditch covered with anti-seepage and anti-evaporation materials. The results was used to accept or reject the hypothesis that it is not cost effective to store one liter of harvested water in a customized ditch than in a traditional plastic tank.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1.` Irrigation Water Quality

The analysed water samples is given on Table 3 and consisted of ten water samples from water pans and ten water samples from boreholes.

Table 3: Irrigation Water Quality from Dams and Boreholes in Isinya Sub County

Parameter	Water Source	Isinya					Kitengela				
Sample		1	2	3	4	5	1	2	3	4	5
pH	Dam water	7.73	7.58	7.87	7.51	8.21	8.34	8.05	7.62	7.88	8.08
	Borehole water	8.05	8.15	8.92	8.34	8.45	8.14	8.4	8.05	8.18	8.14
EC mS/cm	Dam water	0.98	0.29	0.88	1.4	1.76	0.14	0.12	0.08	0.37	1.84
	Borehole water	0.44	1.01	0.86	1.71	0.85	0.39	0.21	0.87	1.17	1.54
Sodium, me/litre	Dam water	7.3	0.52	7.34	8.16	0.85	0.6	0.28	0.82	1.41	8.16
	Borehole water	3	8.2	7.94	14.3	7.7	2.3	1.56	7.9	11.6	14.1
Potassium, me/litre	Dam water	0.34	0.19	0.24	0.23	0.31	0.08	0.11	0.02	0.2	0.41
	Borehole water	0.24	0.38	0.23	0.36	0.21	0.27	0.2	0.86	0.28	0.39
Calcium, me/litre	Dam water	5.62	3.75	5.9	9.36	3.49	3.49	3.34	0.54	6	4.9
	Borehole water	0.9	2.48	4.53	3.48	8.87	0.94	2.38	2.9	2.14	2.96
Magnesium, me/litre	Dam water	0.84	0.73	6.32	2.55	0.53	0.64	0.67	0.09	0.78	1.47
	Borehole water	0.46	0.13	0.03	0.55	6.42	0.31	0.19	5.78	0.81	0.62
Bicarbonates, me/litre	Dam water	7.84	3.96	8.2	7.73	7.6	2.52	2.28	0.61	4.4	5.66
	Borehole water	3.79	6.33	5.4	6.6	8.32	3.48	3.3	8.04	7.76	8.1
Chlorides, me/litre	Dam water	2.8	1.2	2	4.56	6.7	1.3	1.4	1.24	1	7.11
	Borehole water	11.5	3.42	2.84	5.92	2.7	1.16	1.6	2.5	0.4	5.2
Sulphates, me/litre	Dam water	49.4	1.8	33.3	83.9	106	23.5	16.6	7.5	6.6	127
	Borehole water	90.6	34.6	26.2	129	98	59.2	13.6	21.1	45.5	99.3
SAR	Dam water	4.06	0.35	2.97	3.34	0.6	0.42	0.2	1.46	0.77	4.57
	Borehole water	3.64	7.18	5.26	10.1	2.78	2.91	1.38	3.79	9.55	10.5

4.1.1. Irrigation Water Salinity

The findings on water salinity as measured by EC_w on Table 4 below show that some of the borehole water were saline while others were non saline. The same was found in dams and water pans.

Table 4: Electrical Conductivity of Irrigation Water by Source

SAMPLES	Water Source	$EC_{w\ mS/cm}$	Salinity Hazard EC_w mS/cm[1]
DKIT2	Dam	0.08	Non saline
DEXE1	Dam	0.12	Non saline
DQRY1	Dam	0.14	Non saline
B KIT2	Borehole	0.21	Non saline
GKK9	Dam	0.29	Non saline
GKK7	Borehole	0.37	Non saline
BKIT1	Borehole	0.39	Non saline
ISIB2	Borehole	0.44	Non saline
ISI B4	Borehole	0.85	Moderate salinity
GKK2	Borehole	0.86	Moderate salinity
GKK6	Dam	0.87	Moderate salinity
GKK8	Dam	0.88	Moderate salinity
GKK13	Dam	0.98	Moderate salinity
GKK1	Borehole	1.01	Moderate salinity
GKK5	Borehole	1.17	Moderate salinity
ISID1	Dam	1.40	Moderate salinity
GKK4	Borehole	1.54	Moderate salinity
GKK3	Borehole	1.71	High /salinity
ISID2	Dam	1.76	High /salinity
DKIT3	Dam	1.84	High /salinity

Generally, 40% of all the water sources were non saline, 45% were moderately saline and only 15% were severely saline. Of the 40% non-saline water samples, 50% were from dams and 50% from boreholes. Of the 45% moderately saline water, 55.6% of them came from boreholes while 44.4% was from dams. Similarly, of the 15% high salinity water 33.3 % of them was from boreholes while 67.7% was from dams.

Though the stated hypothesis was that all irrigation water in Isinya Sub County is not suitable for irrigated agriculture, the water analysis indicated mixed results with only 15% of the

[1] Non Saline <0.7; Moderately Saline 0.7-1.6; Highly Saline 1.6-3; Very highly Saline >3

irrigation water showing highly saline conditions. The reasons that explain this situation relates to the salt contents in the soil where the boreholes and the dams are situated (Verheye, 2008). The parent rocks in the study area are of mixed nature such as crystalline limestone, quartzites, geniss and granites. There is also an overflow of lava from the volcanic rock on the western side (Sombroek *et al.,* 1982 and Matheson, 1966). The water stored in the dams will over time acquire the characteristics of the carrying soil. Similarly the water from boreholes will over time carry similar characteristics of the parent rock. These may therefore explain the mixed results in both borehole and dam water in Isinya Sub County (Verheye, 2008). Consequently the chemical characteristics of water from different water source are not uniform throughout the region hence mixed results for both borehole and dam water sources in Isinya and Kitengela divisions.

The results of this research can be compared to that of Omran, (2012) and Ndegwa and Kiiru, (2010). Omran (2012) carried out a study to assess and map suitability of well water used for irrigation in Egypt. He found that most of the samples taken from wells were unsuitable for irrigation. Ndegwa and Kiiru, (2010) carried out a study in Turkana district to assess the quality of soil and water used under irrigation in the regions and found that non irrigated fields were not saline on shallow depths but salinity increased with depth from 0.20m. However irrigated fields demonstrated strong salinity on soil surface but salinity decreased with depth.

Similarly Nata *et al.,* (2009) carried out a study in Debre Kidane watershed in Ethiopia to assess groundwater suitability for irrigation purpose and the results indicated the groundwater was suitable for irrigation with some minor exceptions whereby during the rainy season, 89% of the samples were in the water class “good” and 11% “permissible” whereas during the irrigation season only 30% are classified as “good” and 70% under “permissible” class as per the calculation of Irrigation Water Quality Index as provided by Hussain *et al.,* (2014).

These studies compared to the current study show that the characteristics of a given irrigation water depend on location characteristics. Dependence on seasons has also been evaluated by Nata *et al.,* (2009) and found to be a factor that could contribute to varying chemical properties of irrigation water. This therefore imply that irrigation water quality differ in space and time and therefore each irrigation system need to carry out a baseline study at the onset of irrigation project; and that frequent studies on quality need to be undertaken at periodic intervals to allow for strategic management of soil and water conditions.

4.1.2. Irrigation Water Sodium and SAR

The sodium hazard in the irrigation water was measured by Sodium Adsorption Rate (SAR), which measures the amount of sodium relative to calcium and magnesium in water. SAR measure gives an indication of how irrigation water may affect soil such as the swelling and dispersion of soil clays, surface crusting and pore plugging.

The results of the SAR are given in Table 5 and show that 50% of all the water sampled had low SAR while 35% had moderate SAR and 15% had a high SAR. The 50% low SAR water, 60% of them were from dams and 40% from boreholes. The 35% moderate SAR water, 57.1% were from dams and 42.9% were from boreholes. All the high SAR water was sourced from boreholes. Generally boreholes therefore seemed to show higher SAR than dam water.

Table 5: Sodium Hazard on the Basis of SAR

SAMPLES	Source	SAR	Sodium Hazard[2]
DKIT3	Dam	0.2	Unlikely
GKK9	Dam	0.35	Unlikely
DKIT2	Dam	0.42	Unlikely
BKIT1	Borehole	1.46	Unlikely
DEXE1	Dam	0.6	Unlikely
GKK7	Borehole	0.77	Unlikely
ISI B4	Borehole	1.38	Unlikely
ISIB2	Borehole	2.91	Unlikely
ISID2	Dam	3.64	Likely
GKK13	Dam	4.06	Likely
GKK8	Dam	2.97	Unlikely
DQRY1	Dam	2.78	Unlikely
GKK6	Dam	3.79	Likely
GKK2	Borehole	5.26	Likely
B KIT2	Borehole	4.57	Likely
ISID1	Dam	3.34	Likely
GKK1	Borehole	7.18	Likely
GKK5	Borehole	9.55	Very Highly likely
GKK4	Borehole	10.5	Very Highly likely
GKK3	Borehole	10.1	Very Highly likely

However, according to Ayers and Westcot, (1994) the suitability of the irrigation water cannot be adequately assessed on the basis of the SAR alone. This is because at a given SAR level the

[2] Sodium Hazard Unlikely <3.0 ; slight to moderate 3-9 very highly likely >9

infiltration rate increases as salinity increases and vice versa. Therefore, a more accurate evaluation of the infiltration/permeability hazard requires using the electrical conductivity (EC_w) together with the SAR as demonstrated in Table 6 below. As recommended by Ayers and Westcot (1994), the analyzed results indicated that 50% of all the water was suitable while 50% were unsuitable. The suitable water comprised 40% sourced from dams and 60% sourced from boreholes. In the unsuitable category 60% were sourced from dams and 40% from boreholes.

Table 6: SAR and EC_W Irrigation Water Quality

SAMPLES	Source	$EC_{w\ mS/cm}$	SAR	Condition of Sample[3]
DKIT3	Dam	1.84	0.2	Unlikely
GKK9	Dam	0.29	0.35	Likely
DKIT2	Dam	0.08	0.42	Likely
BKIT1	Borehole	0.39	1.46	Likely
DEXE1	Dam	0.12	0.6	Likely
GKK7	Borehole	0.37	0.77	Likely
ISI B4	Borehole	0.85	1.38	Likely
ISIB2	Borehole	0.44	2.91	Likely
ISID2	Dam	1.76	3.64	Likely
GKK13	Dam	0.98	4.06	Unlikely
GKK8	Dam	0.88	2.97	Unlikely
DQRY1	Dam	0.14	2.78	Unlikely
GKK6	Dam	0.87	3.79	Unlikely
GKK2	Borehole	0.86	5.26	Likely
B KIT2	Borehole	0.21	4.57	Likely
ISID1	Dam	1.4	3.34	Unlikely
GKK1	Borehole	1.01	7.18	Unlikely
GKK5	Borehole	1.17	9.55	Unlikely
GKK4	Borehole	1.54	10.5	Unlikely
GKK3	Borehole	1.71	10.1	Unlikely

The above results were similar to that reported by Nishanthiny *et al.,* (2010) whose findings were that based on EC_w, 44% of the water from wells had medium salinity water, 47 % had

[3] If SAR is: 0-3 3-6 6-12 12-20 20-40 and EC (dS/m) is: >0.7 >1.2 >1.9 >2.9 >5.0 then sodium hazard is unlikely. If SAR is: 0-3 3-6 6-12 12-20 20-40 and EC (dS/m) is <0.2 0.3 0.5 1.3 2.9 then sodium hazed is likely

high salinity water and 9 % had very high salinity water. Based on sodium, 3% of the water from wells had excellent irrigation water quality, 18 % had good irrigation water quality, 44% had permissible irrigation water quality, 32% had doubtful irrigation water quality and 3% had unsuitable irrigation water quality. Based on SAR, almost all the water from well s had good quality irrigation water.

4.1.3. Toxicity Problems in Irrigation Water

To evaluate toxicity problems in irrigation water, concentrations of sodium, chloride, and bicarbonate were analyzed in the water samples. The results for chloride toxicity shown on Table 7 indicated that 14 samples (70%) of all the water samples were suitable for surface irrigation, 5 samples (25%) moderately suitable while one sample (5%) was found to be unsuitable for surface irrigation.

Table 7: Chloride Toxicity in Irrigation Water

Sample	Source	Chloride me/l	Toxic for Surface Irrigation[4]	Toxic for Sprinkler Irrigation[5]
GKK5	Borehole	0.4	None	None
GKK7	Borehole	1	None	None
ISIB2	Borehole	1.16	None	None
GKK9	Dam	1.2	None	None
BKIT1	Borehole	1.24	None	None
DKIT2	Dam	1.3	None	None
DKIT3	Dam	1.4	None	None
ISI B4	Borehole	1.6	None	None
GKK8	Dam	2	None	None
GKK6	Dam	2.5	None	None
DQRY1	Dam	2.7	None	None
GKK13	Dam	2.8	None	None
GKK2	Borehole	2.84	None	None
GKK1	Borehole	3.42	None	Moderate
ISID1	Dam	4.56	Moderate	Moderate
GKK4	Borehole	5.2	Moderate	Moderate
GKK3	Borehole	5.92	Moderate	Moderate
DEXE1	Dam	6.7	Moderate	Moderate
B KIT2	Borehole	7.11	Moderate	Moderate
ISID2	Dam	11.5	Severe	Moderate

The results for sodium toxicity as shown on Table 8 indicated 9 water samples (45%) were suitable for irrigation while 8 samples (40%) showed moderate tendencies towards sodium toxicity. The rest 3 samples (15%) were toxic and unsuitable for irrigation. The 45% that were suitable were sourced from dams (55.6%) and from boreholes (44.4%. The 40% samples that

[4] Chloride toxicity for surface irrigation: None<4; moderate 4-10; severe >10

[5] Chloride toxicity for sprinkler irrigation: None<3; moderate >3

were moderate were from the dams (62.5%) and boreholes (37.5%). The 15% samples that showed sodium hazard were from boreholes.

Table 8: Sodium Toxicity in Irrigation Water

			Toxicity
Sample	Source	Sodium, me/litre	None
DEXEL1	Dam	0.28	None
GKK 9	Dam	0.52	None
DQRY1	Dam	0.6	None
DKIT2	Dam	0.82	None
ISID2	Dam	0.85	None
GKK 7	Borehole	1.41	None
B KIT2	Borehole	1.56	None
B KIT1	Borehole	2.3	None
ISIB2	Borehole	3	None
GKK13	Dam	7.3	Moderate
GKK 8	Dam	7.34	Moderate
ISI B4	Borehole	7.7	Moderate
GKK 6	Dam	7.9	Moderate
GKK2	Borehole	7.94	Moderate
ISID1	Dam	8.16	Moderate
DKIT3	Dam	8.16	Moderate
GKK1	Borehole	8.2	Moderate
GKK 5	Borehole	11.6	Severe
GKK4	Borehole	14.1	Severe
GKK3	Borehole	14.3	Severe

Research done that is similar to this study in the context of sodium toxicity include that by Joshi *et al.,* (2009) which evaluated the quality of irrigation water sourced from river Ganga in Haridward District India and found high levels of sodium content measured in terms of sodium percent to range from 23.56 to 52.35 during the rainy season but were within suitable limits when there were no rains.

The bicarbonate hazard evaluation for irrigation water shown in Table 9 indicated that only one (5%) water sample was suitable and it was sourced from a dam. Two samples (10%) were moderate and were also sourced from dams. The rest 17 (85%) were found toxic and unsuitable for irrigation. Out of these 17 samples those sourced from dams were 6 (35.3%) compared to 11(64.7%) from boreholes

Table 9: Bicarbonate Toxicity Irrigation Water

Sample	Source	HCO3me/l	Toxicity[6]
DKIT2	Dam	0.61	None
DEXEL1	Dam	2.28	Moderate
DQRY1	Dam	2.52	Moderate
B KIT2	Borehole	3.3	Severe
B KIT1	Borehole	3.48	Severe
ISIB2	Borehole	3.79	Severe
GKK 9	Dam	3.96	Severe
GKK 7	Borehole	4.4	Severe
GKK2	Borehole	5.4	Severe
DKIT3	Borehole	5.66	Severe
GKK1	Borehole	6.33	Severe
GKK3	Borehole	6.6	Severe
ISID2	Dam	7.6	Severe
ISID1	Dam	7.73	Severe
GKK 5	Borehole	7.76	Severe
GKK13	Dam	7.84	Severe
GKK 6	Dam	8.04	Severe
GKK4	Borehole	8.1	Severe
GKK 8	Dam	8.2	Severe
ISI B4	Borehole	8.32	Severe

The above results were similar to the work done by Kumar *et al.*, (2007) that found a high concentration of bicarbonate in groundwater used for irrigation in Punjab district of India. Islam attributed this high concentration to weathering process within the location resulting from underlying parent rock.

4.2.Effects of Irrigation on Soil Chemical properties

The results of the laboratory analysis were organized according to the soil sources as shown on Appendix 3. ANOVA statistical analysis in GENSTAT was carried out and the results were as shown on the Table 10 below.

[6] Degree of bicarbonate toxicity: None <1.5; Moderate 1.5-3; Severe >3

Table 10: Mean Values for the Analyzed Soil Parameters

Irrigation Treatments	pH	Ec ds/m	HCO_3	Chloride	Ca	Mg	Na	K	SAR
Borehole	7.73a	1.03a	0.8067a	2.02a	1.83a	0.7175a	2.26b	0.051a	2.09b
Dam	7.08a	0.62a	0.8187a	1.47a	1.22a	0.8422a	1.29a	0.031a	1.33ab
Control	6.81a	0.44a	0.8468a	1.51a	1.5a	0.7581a	0.74a	0.038a	0.79a
LSD	1.172	0.667	0.1953	0.632	0.790	0.3454	0.856	0.021	0.858
CV%	8.100	48.0	11.9	19.000	26.100	22.4	30.000	27.2	30.600

The results from the ANOVA indicate that the changes in soil pH as a result of irrigation was not significant after irrigating with borehole and dam water. The changes in EC were also not significant for both borehole and dam water.

The analysis for changes as a result of irrigation on toxic elements indicated no significant results for chlorides and bicarbonate from irrigation with both borehole and dam water, but indicated significant changes for sodium and its SAR value from irrigation with borehole and dam water.

The studies that have been done in Kenya include that Ndegwa and Kiiru, (2010) who investigated the effect of irrigation on water and soil quality in Turkana district by comparing non irrigated with periodically irrigated and intensely irrigated soils at different depths The results of their research were mixed results with some means not significantly different, but were all significantly different at the upper 0.20 m soil depth. Ndegwa and Kiiru, 2010 also found that at 0.40 m soil depth, intensively irrigated fields showed significantly difference from both non irrigated and periodically irrigated fields.

Other similar researches include that of Mon *et al.*, (2007) who studied the effects of supplementary irrigation on soil chemical and physical properties in the rolling Pampa region of Argentina by comparing irrigated and non-irrigated soils. In irrigated soils, chemical data shows, on average, a slight increase in pH (from 6.13 to 6.45). EC, showed the same values in irrigated and non-irrigated soils. The statistical analysis of comparing means of irrigated and non-irrigated soils indicated not significant change in EC and pH.

Heidarpour *et al.*, (2007) studied the effects of wastewater on soil chemical properties using two irrigation methods in central Iran. The findings were that the soil EC, Na and Mg of the first layer of soil (0–15 cm) were significantly greater with subsurface irrigation than with surface irrigation. The EC, Na and Mg of second and third soil layers irrigated with wastewater were less as compared with groundwater. The amount of K in the first and second soil layers irrigated with wastewater was significantly greater than those irrigated with groundwater. There was no significant effect on soil Na, P and TN due to irrigation with wastewater.

Other studies focused only on highlighting the effects by making comparison without statistical analysis. Examples included that done by Cucci *et al.,* (2013) which found that the use of irrigation water with 0.1 M salt concentration caused an increase in (ECe) from an initial average value of 0.71 dS m-1 to 13.9 and 19.5 dS m-1, at the end of the first and the second irrigation season with small variation in pH. Other similar studies included Getaneh *et al.,* (2007) who carried out a study to investigate the effects of small scale irrigation on selected soil chemical properties in sub-humid agro-ecosystem of Ethiopia to compare irrigated farmland and the adjacent non-irrigated farmlands. The results of the study indicated that soil pH, and exchangeable bases were higher in irrigated farmlands than the non-irrigated farmlands.

Adejumoki *et al.,* (2014) to study the effects of irrigation practices on the soils of Omi irrigation scheme Kogi state, Nigeria after 13years of operation. The analysis carried out revealed that the soil of the scheme has been affected due to changes in some chemical characteristics measured in the field compared to its baseline, such as pH which was in the neutral range at the inception of the scheme but reduced to being slightly acidic, while macronutrients such as Ca2+and Mg2+ reduced compared to the baseline.

Mostafazadeh- Fard *et al.,* (2007) carried out an experiment to determine the effects of irrigation water salinity and different levels of leaching on some soil chemical properties The results showed that as the irrigation water salinity increased the soil salinity and soil sodium adsorption ratio increased The increase in irrigation water salinity had no effect on the soil acidity, but it decreased the water holding capacity.

4.3.Green House Top Rainwater Harvesting

4.3.1. Amount of Rainwater Harvested

The actual amount of water collected for each rainfall event in each of the three greenhouse tops was recorded Table 11 below.

Table 11: Total Daily Volume of Rainwater Harvested

	Greenhouse 1		**Greenhouse 2**		**Greenhouse 3**	
Day	**Volume (m^3)**	**Rainfall (mm)**	**Volume (m^3)**	**Rainfall (mm)**	**Volume (m^3)**	**Rainfall (mm)**
1	1.0752	8	2.5	7	0.6912	6.1
2	0.1506	1	3.4202	6	0.4338	2.4
3	2.088	12	1.3248	10	0.43945	5.8
4	0.853272	5.2	2.275	5.5	0.554	2.8
5	0.3562	2	1.485	4	1.234542	8.2
6	2.43164	12	2.12	7	1.477216	10.1
7	0.34176	2.1	0.555	2	1.129842	1.5
8	0.383328	1.55	0.565	1.5	0.502448	4.2
9	0.863232	9	4.235	12	0.877344	6
10	0.128968	7.8	2.3688	6	0.077958	0.5
11	0.5616	4.6	1.6512	4.5	0.7974	6
12	0.2862	2.6	6.705	19	2.5866	13.6
13	9.2168	9.1	4.075	9	2.389272	18.1
14	15.30325	17.78	7.04	18	5.288928	33.8
15	13.56075	28.99	11.76	30	5.80125	35.8
16	11.561	12	4.24	13	1.47	15.5
17	7.40025	12.2	11.3	23	13.254318	88
Total Harvest in m^3	66.56205		67.62		39.005568	
Total Surface Area in m^2	188.52		540.424		188.52	
Total Rainfall (mm)		147.92		177.5		258.4
Volume per 1mm rainfall	0.44998		0.3809		0.1509	
Volume (m^3) per 1mm rainfall on $1m^2$ surface area	**0.00238***		**0.000705**		**0.0008**	
Average Volume in lm^3 per 1mm rainfall per $1m^2$ surface area					**0.00075**	

In Greenhouse 1, a total of 66.562m^3 of water was harvested while in Greenhouse 2, a total of 67.620m^3 were harvested, and Greenhouse 3 yielded a total of 39.005m^3. The volume harvested from 1m^2 surface area when it rained 1mm of rainfall were therefore 0.0024m^3 for greenhouse 1; 0.0007m^3 for greenhouse 2 and 0.00080m^3 for greenhouse 3. The average collection for 1mm of rainfall on 1m^2 surface area of the three Greenhouse top was therefore 0.00128m^3. However in view of the big difference between Greenhouse1 mean and the other means, it became imperative to ignore the data from Greenhouse 1. Therefore based on Greenhouse 2 and 3 averages, it can be concluded that it is possible to harvest an average of $0.00075m^3$ of water when it rained 1mm of rainfall falling on $1m^2$ of Greenhouse rooftop.

The amount of water harvested from each greenhouse daily were correlated with each of its own rainfall recording. Greenhouse 1 Correlation Factor was 0.6445, Greenhouse 2 was 0.9199 and Greenhouse3 was 0.9855 as shown on Figure 1, 2 and 3 below. These results demonstrated a positive correlation between daily amount of rain harvested and daily rainfall measurements.

Greenhouse 1 demonstrated a weaker positive correlation while 2 and 3 demonstrated very strong positive correlation. Greenhouse 1 mean was also markedly different from the rest. This indicate that there may have been errors in recording either the daily amount of rainfall of the daily volume of rainwater harvested.

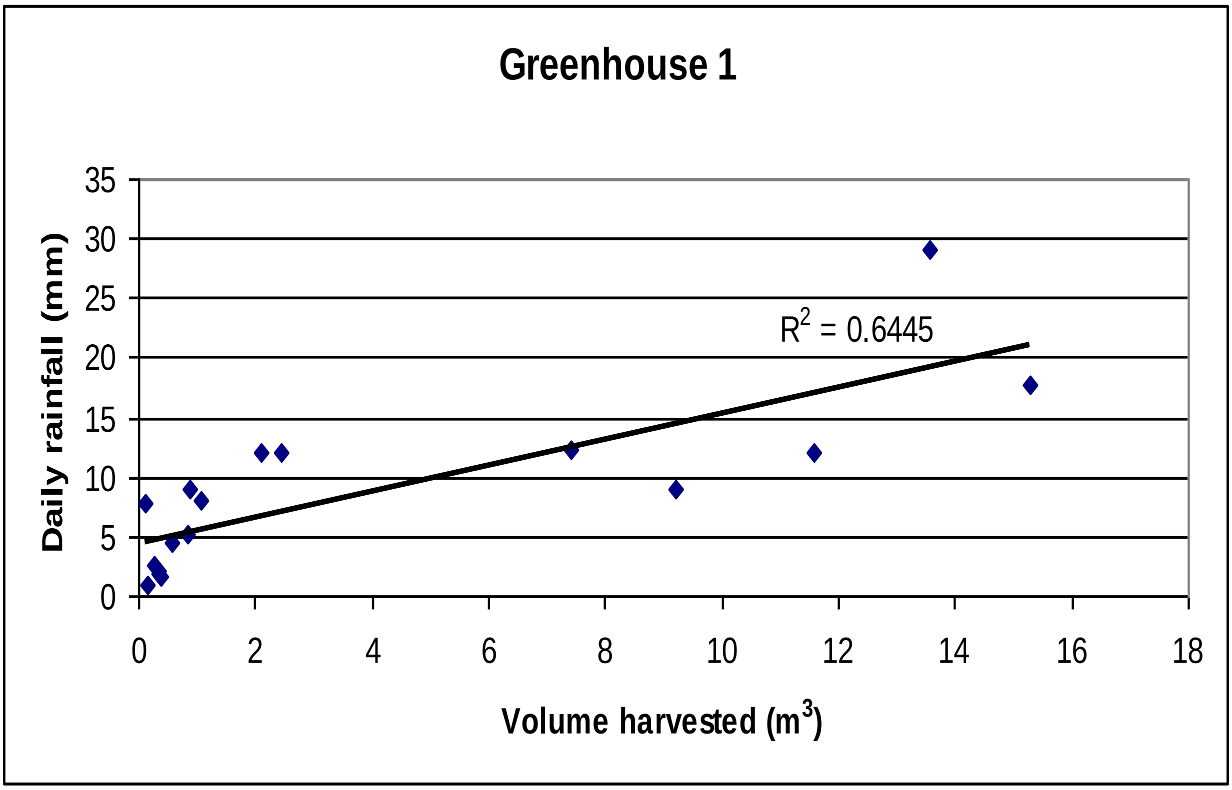


Figure 4: Greenhouse 1 volume harvested and rainfall correlation

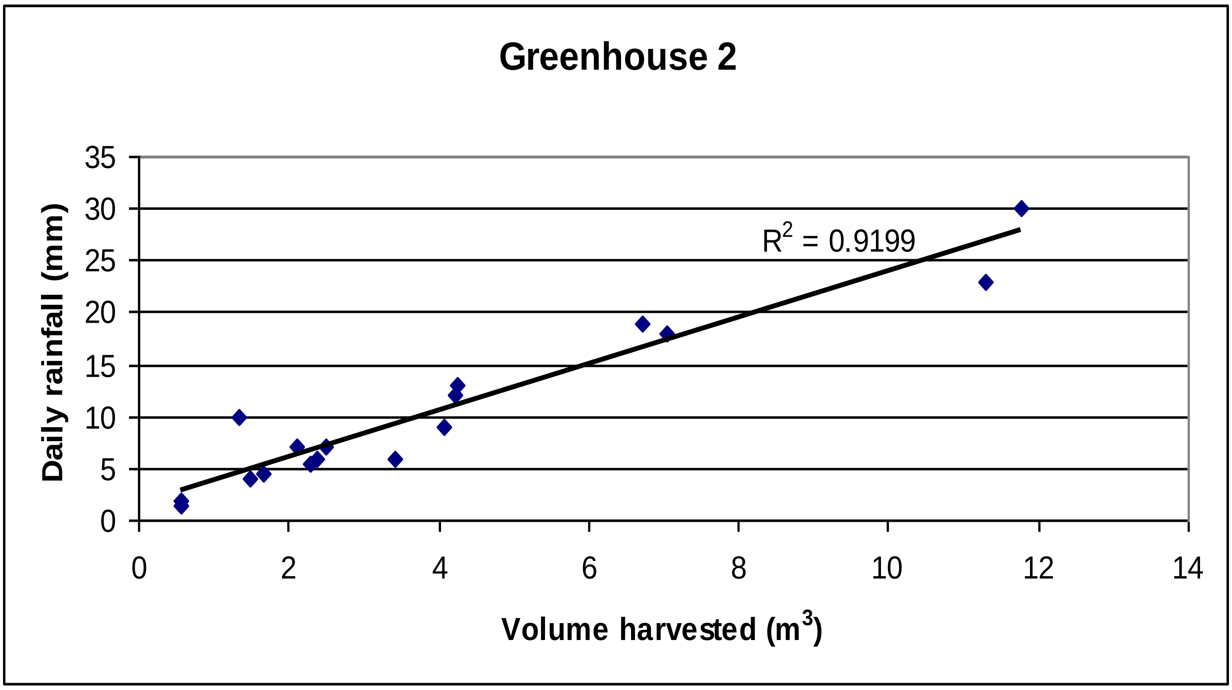


Figure 5: Greenhouse 2 Volume harvested and rainfall correlation

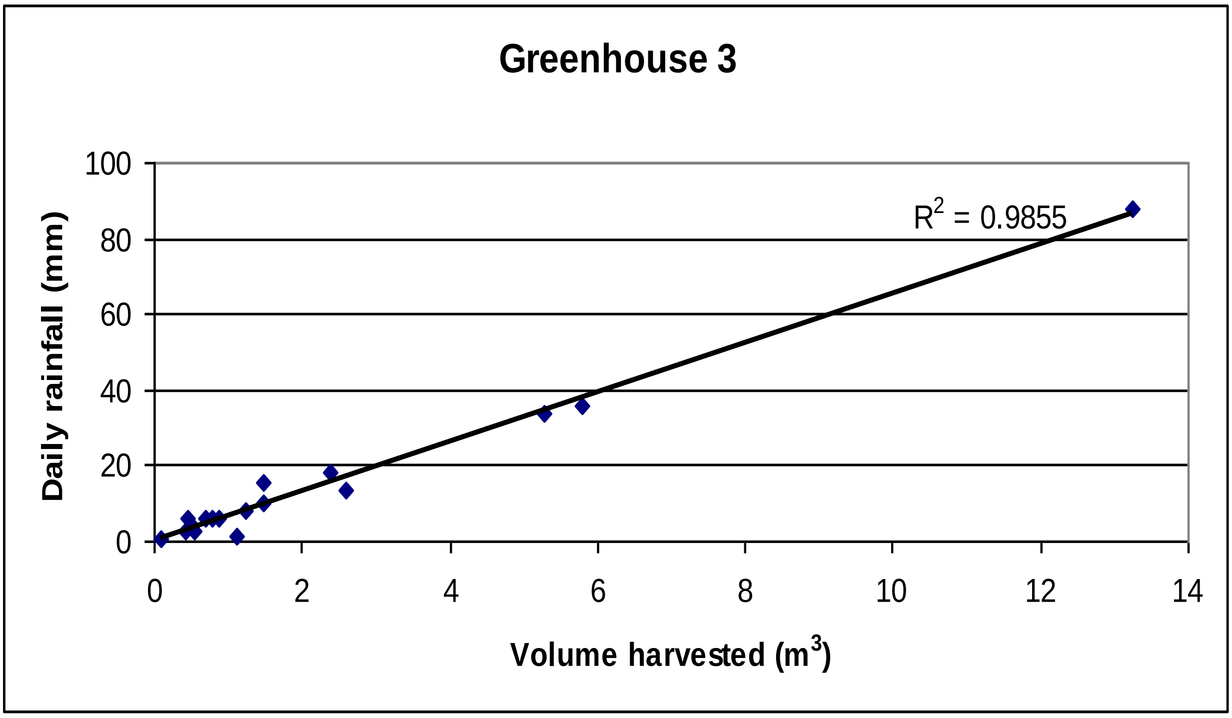


Figure 6: Volume Greenhouse 3 harvested and rainfall correlation

Accordingly, in Isinya sub-county, smallholder farmers have the potential to harvest an average of 0.00075m^3 of rainwater whenever it rained 1mm rainfall falling on 1m^2 of a greenhouse top and collected into a customized dug out ditch lined with an anti-seepage material.

These results are consistent with the study carried out by Patel *et al.*, (2014) in SPCE, Visnagar India with the main objective of evaluating possible amount of water that could be harvested from campus rooftops. The research team were able to harvest a total of 266,672.37m^3 of rain water falling on 31,342.28m^2 of surface area with the average annual rainfall of 750mm.

Aladenola and Adeboye, (2010) carried out a study to assess the potential for rainwater harvesting for Abeokuta region in Nigeria. The findings were that with an annual mean rainfall of 1156mm it was possible to harvest annually approximately 74.0 m^3 of rainwater per household whose rooftop was an average of 80m^2.

Kahinda *et al.,* (2010) did a study to presents a methodology that enables water managers to incorporate the climate change component during the design phase of Domestic Rain Water Harvesting (DRWH) systems. The Roof model was used to calculate the optimum size of the Rain Water Harvesting (RWH) storage tank and appraise its water security which was found about 30%. On the basis of forecasted rainfall water security attained by a 0.5 m^3 RWH tank was found between10–15% in the arid areas, 15–20% in both the semi-arid and dry sub humid areas and 30–40% in the humid zones.

Sharma *et al.,* (2013) carried out a study in the horticultural farm in Athi River outside Nairobi, Kenya. The area experienced sodicity problems which necessitated identification of a clean source of water. The solution was rainwater harvesting, storage and usage. Rainwater harvesting provided 60% of its annual irrigation water requirement of an average about 300,000 m^3. Without rainwater harvesting, the company could have had to sink four extra boreholes to efficiently irrigate the 30 hectares of roses .The company uses three types of rainwater harvesting techniques; namely, rooftop, surface runoff and flood flow water harvesting. The study concluded that Rainwater harvesting and its storage would be an effective solution for both commercial and subsistence farmers.

Kimiti, (2007) carried out a similar study in Machakos to investigate the characteristics of rainfall and to quantify the probable volume of water that can be harvested from rainfall inputs. The study differed markedly from the current study in terms of methodology. Rainfall data for the study area was obtained from the Kenya Meteorological department with missing data being estimated using the linear interpolation formula. Similarly, roof catchments areas were determined through exploratory survey of the area of study. The findings indicated high variability of temporal distribution of rainfall over the years in all stations.

4.3.2. Cost of Harvesting and Storing Rain Water.

The total costs of constructing and maintaining the rainwater harvesting and storage system was calculated and it was a total of Kshs 157,904 for the three greenhouses as shown in Table 12 below. Three water storage ditches were dug and prepared at a total costs of Ksh 157,904.00. The cost for each greenhouse ditch was an average of Ksh 52,635.00. The cost for each greenhouse was compared to the total amount of water actually harvested. The findings were that the average cost for storing one cubic meter of water in the ditch was Ksh 972.85.

Table 12: Cost of Rain Water Harvesting and Storage

	Volume Harvested (m^3)	Costs (Kshs) per greenhouse	Cost per m^3 per greenhouse (Kshs)
Green House 1 – Kitengela	66.562	52,634.67	790.76
Green House 2 – Kitengela	67.620	52,634.67	778.39
Green House 3 – Isinya	39.005	52,634.67	1349.41
Average Storage Cost per m^3			**972.85**

A comparative cost analysis was carried out to compare the costs of storing the same volume of rain water using the customized ditch for the same volume of water using the traditional plastic tanks (Table 13). The findings indicate that it costs Kenya shillings 4850 to store same amount of water in a plastic tank compared to Kenya shillings 972.85 using a dugout ditch. The cost of the plastic tanks does not include transport and installation costs, while the ditch costs also assumes costs of constructing the greenhouse.

Table 13: Key Water Storage Tank Manufactures and Costs

Storage Device	**Storage Capacity (cubic meters)**	**Total Cost of Storage**	**Storage Cost per cubic meters (KSh)**
Toptank	5	40500	8100
Zentank	5	38300	7660
Polytank	5	34200	6840
Roto Tank	5	45000	9000
Average per Tank	5		7900
Customized Ditch	5	4850	970

The results of this study was compared to a research project that was carried out to facilitate the design of very-low-cost domestic roof water harvesting in the humid tropic (DFID, 2002). The research was carried out in three countries of Sri Lanka, Ethiopia and Uganda where rural communities experience challenges in storing rain water. The results of this research provided data that guide the design of low cost rainwater storage facilities. Some of the recommendations include the tarpaulin tank as an example of a successful low cost design that is being replicated in southern Uganda. This design is closely related to the dugout ditch lined with a polythene material.

In Bangladesh Islam *et al.,* (2014) carried out a research to investigate the prospect of rainwater harvesting as a low cost alternative potable water supply option along the coastal region of Bangladesh. The findings were related to the present research and recommended that the minimum catchment's area required for collection of rainwater for a rural household was found to be 6 m^2 for the annual water requirement of a rural family of six members was calculated as 11 m^3. Water demand was calculated as two thousand liters for a six to seven member family. A low cost rain water harvesting and storage system was proposed at a cost of $171 which was assumed to be affordable in the region. This is roughly equivalent to Kenya shillings 17100 by current rates. The current design cost Kenya shillings 157, 904.00 is even lower than that of Bangladesh.

India has carried out extensive rain water harvesting projects in various regions documenting everything. Two examples stand out. These are the Panscheel Cooperative Group housing Society who set up rainwater harvesting from the roof top of buildings in their colony. The total surface collection area of the roofs was 357,150m^2 located in an area receiving 611mm rainfall annually. They collected a total of 174,575m^3 of water at a total cost of Rs. 800,000.00. This is equivalent to Rs 4.582 per cubic metre or Kenya shillings 6.87 per cubic metre. The rooftop collection efficiency was 80%. In another of their project, Mother Dairy F & V Unit located in the same region they collected a total of 322, 249.802m^3 of water from 89,370m^2 at a total cost of Rs. 435,000 equivalent of Rs. 1.35 per liter or Kenya shillings 2.00 per liter.

Babu, (2010) set up a rain water harvesting project on Roof top to implement a safe drinking water to the community with the aim to identify the best possible technology. The study revealed that, it requires community acceptance, maintenance and time involvement for effective utilization and the water available at the door step at a total cost of Rs. 1300/- per cubic metre which is equivalent to Kenya shillings 1950 per cubic metre.

On the other hand one study carried out in the USA indicated that it was not cost effective to harvest rain water in comparison with municipal water. Hicks, (2008) carried out economic analyses from the perspective of a private developer using two case studies of commercial developments in Arlington. The results of this study suggest that the benefits of incorporating rainwater harvesting into building designs do not justify the cost of implementing this technique. It did not readily show a positive economic cash flow even though a system could be constructed to effectively harvest rainwater and distribute it throughout the building. However the results also showed that if even a modest price premium can be achieved for a given project the economic analysis drastically changes to a positive return to investing in rainwater harvesting.

In Ghana, Kaboh-bah *et al.*, (2008) described a collaborative research effort that was aimed at the adaptation and development of affordable technologies for capturing and retaining rainwater runoff including that from roof tops in Northern Ghana. The results of this study have not been published as yet.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The results of this study indicated that, subject to a number of considerations, sustainable irrigation systems can improve dry land agriculture. Smallholder farmers in dry lands can embrace irrigation, but they need to be aware of the following dependent factors:

1. The quality of irrigation water regardless of the source have unique qualities that are characteristic of that location in terms of its underlying basement rock and soil chemical properties of that particular location. There are no generalities as per as the quality of a given source of irrigation water and a keen farmers needs to understand this factor before engaging in irrigation. In the study area, irrigation water was considered moderately suitable on all aspects except on bicarbonate, sodium and SAR.
2. The study also concluded that irrigation in dry lands affect the chemical characteristics of soil in varying degrees depending on the chemical properties of the irrigation water. Specifically, the study concluded that the effects of irrigation on soil chemical properties was significant for sodium and SAR in the study area.
3. Finally the study concluded that rainwater harvesting in the dry lands offers a viable option of obtaining irrigation water. Each rainfall event has the capacity to produce adequate amount of water for irrigation. In addition the study concluded that it is affordable to store the harvested rainwater in a customized underground ditch made with locally available resources as opposed to storing in commercially available water tanks such as plastics.

5.2. Recommendations

The overall recommendation of this study therefore was that for sustainable smallholder irrigation, farmers need to carry out baseline study of the proposed irrigation water and the soils of the proposed farm in order for them to design a sustainable irrigation management system. This means carrying out laboratory chemical analysis of both soil and water of the intended irrigation system before the start of the irrigation project. The same farmers too can consider harvesting rain water and storing them in underground ditches constructed with locally available materials at affordable costs.

On the basis of the findings relating to the fact that irrigation water in the area was considered moderately suitable on all aspects except on sodium and SAR, it is recommended that farmers in Isinya adopt measures to manage sodium hazard in any intended irrigation scheme. These may include the use of gypsum and leaching subject to further analysis to determine exchangeable sodium and leaching requirements. Other measures may include the use of organic matter to stabilize soil structure and promote effective leaching.

Likewise the effects of irrigation water on the soil chemical parameters was significant for sodium and SAR. It is recommended therefore that farmers employ soil management practices that will reduce sodium hazards such as use of gypsum and organic matter as well as leaching.

Further to the findings on rainwater harvesting, it is recommended that farmers could overcome the effects of irrigation by use of borehole and dam water by embracing rainwater harvesting as a source of irrigation water since rainwater harvesting and storage is a viable option that can be embraced by smallholder farmers.

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APPENDICES

Appendix 1: Laboratory Guidelines for Evaluating Irrigation Water Quality

Water parameter	Symbol	Unit	Usual range in irrigation water	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO^{--}_3	me/l	0 – .1	me/l
Bicarbonate	HCO_3^-	me/l	0 – 10	me/l
Chloride	Cl^-	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio	SAR	(me/l)	0 – 15	

Adapted from Ayers and Westcot, 1994

Appendix 2: Results of Water Samples Laboratory Analysis by Source

				Me/l						
Lab Code	Sample Code	Ph	Ec ds/m	HCO3	Chloride	Ca	mg	Na	K	SAR
625	MRTC T3	8.01	3.90	0.89	3.80	1.80	0.95	3.96	0.046	3.37
626	MTRC T2	8.02	0.20	0.99	2.10	2.65	0.89	2.09	0.068	1.45
627	MTRC T1	8.20	0.20	0.79	1.30	2.70	0.99	1.57	0.069	1.07
628	MTRC C1	6.80	0.60	0.70	1.60	1.55	0.75	0.61	0.04	0.57
629	MTRC C2	6.61	0.20	0.90	1.10	1.20	0.54	0.52	0.03	0.56
630	MTRC C3	6.53	0.70	0.60	1.20	0.40	0.26	0.96	0.01	1.67
631	EMPI C1	7.10	0.40	0.80	1.20	0.50	0.09	0.96	0.01	1.76
632	EMPI C2	6.98	0.20	0.70	1.00	0.20	0.35	0.78	0.01	1.49
633	EMPI C3	7.80	0.60	2.40	1.40	0.80	0.28	1.17	0.02	1.60
634	EMPI T1	7.50	1.30	1.00	1.50	1.40	0.68	1.83	0.04	1.79
635	EMPI T2	7.54	1.15	0.90	1.40	0.90	0.34	1.91	0.02	2.43
636	EMPI T3	7.83	1.00	0.87	2.80	2.40	1.35	2.52	0.06	1.84
637	QRY C1	7.50	0.20	0.90	1.30	1.60	0.81	0.48	0.04	0.44
638	QRY C2	7.52	0.20	0.10	1.20	2.00	1.08	0.52	0.05	0.42
639	QRY C3	7.02	0.30	0.90	1.20	1.80	0.95	0.70	0.05	0.59
640	QRY T1	7.29	0.35	0.70	1.00	1.90	1.01	0.87	0.05	0.72
641	QRY T2	7.05	0.30	0.60	1.20	0.10	0.58	0.78	0.003	1.34
642	QRY T3	7.15	0.40	0.80	1.30	0.90	1.25	0.96	0.02	0.92
643	KEKIDS C1	7.58	0.50	1.60	1.70	2.60	1.28	1.04	0.07	0.75
644	KEKIDS C2	6.90	0.20	1.10	1.10	2.30	0.41	0.70	0.06	0.60
645	KEKIDS C3	6.46	0.40	0.20	2.40	1.00	1.35	0.65	0.03	0.60
646	KEKIDS T1	8.11	1.65	1.00	2.70	2.40	0.64	2.35	0.06	1.90
647	KEKIDS T2	8.64	0.30	0.99	1.70	1.00	0.10	2.35	0.03	3.17
648	KEKIDS T3	8.24	0.50	0.10	1.60	0.50	0.65	2.00	0.01	2.64
649	EXCEL T1	7.04	0.35	1.00	1.30	1.05	0.49	0.91	0.027	1.04
650	EXCEL T2	5.96	0.45	0.80	1.30	1.25	0.66	1.04	0.032	1.07
651	EXCEL T3	6.38	0.30	0.60	1.40	1.10	0.94	0.78	0.028	0.77
652	EXCEL C1	7.01	0.30	0.80	1.00	1.20	0.41	0.57	0.03	0.63
653	EXCEL C2	7.26	0.20	0.90	1.00	0.55	0.54	0.61	0.01	0.82
654	EXCEL C3	7.00	0.45	1.10	2.10	1.90	0.15	0.78	0.04	0.77
655	SINKEET C1	6.98	0.20	1.12	1.20	1.00	0.54	1.22	0.04	1.39
656	SINKEET C2	7.20	0.20	0.70	1.20	1.05	0.65	1.17	0.03	1.27
657	SINKEET C3	7.10	1.60	1.10	1.00	1.80	0.58	2.26	0.05	2.07
658	SINKEET T1	7.13	0.55	0.81	1.20	1.20	1.02	2.17	0.04	2.06
659	SINKEET T2	7.20	1.50	1.00	2.50	3.00	0.58	2.78	0.08	2.08
660	SINKEET T3	6.05	0.45	0.80	1.30	1.22	0.64	1.04	0.07	1.08

Appendix 3: The Effects of Irrigation Water on Chemical Soil Properties

		pH		Ec ds/m		HCO3		Chloride		Ca		mg		Na		K		SAR	
Farm	Sample Code	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated	Not irrigated	Irrigated
Farm 1	MRTC T3	6.80	8.01	0.60	3.90	0.70	1.10	1.60	3.80	1.55	1.80	0.75	0.95	0.61	3.96	0.04	0.05	0.57	3.37
	MTRC T2	6.61	8.02	0.20	0.20	0.90	1.30	1.10	2.10	1.20	2.65	0.54	1.52	0.52	2.09	0.03	0.07	0.56	1.45
	MTRC T1	6.53	8.20	0.70	0.20	0.60	1.10	1.20	1.30	0.40	2.70	0.26	1.55	0.96	1.57	0.01	0.07	1.67	1.07
Farm 2	KEKIDS T1	7.58	8.11	0.50	1.65	1.60	2.90	1.70	2.70	2.60	2.40	1.28	0.64	1.04	2.35	0.07	0.06	0.75	1.90
	KEKIDS T2	6.90	8.64	0.20	0.30	1.10	1.30	1.10	1.70	2.30	1.00	0.41	0.10	0.70	2.35	0.06	0.03	0.60	3.17
	KEKIDS T3	6.46	8.24	0.40	0.50	0.20	0.10	2.40	1.60	1.00	0.50	1.35	0.65	0.65	2.00	0.03	0.01	0.60	2.64
Farm 3	SINKEET T1	6.98	7.13	0.20	0.55	1.12	0.81	1.20	1.20	1.00	1.20	0.54	1.02	1.22	2.17	0.04	0.04	1.39	2.06
	SINKEET T2	7.20	7.20	0.20	1.50	0.70	1.00	1.20	2.50	1.05	3.00	0.65	0.58	1.17	2.78	0.03	0.08	1.27	2.08
	SINKEET T3	7.10	6.05	1.60	0.45	1.10	0.80	1.00	1.30	1.80	1.22	0.58	0.64	2.26	1.04	0.05	0.35	2.07	1.08
Farm 4	EMPI T1	7.10	7.50	0.40	1.30	0.80	1.00	1.20	1.50	0.50	1.40	0.09	0.68	0.96	1.83	0.01	0.04	1.76	1.79
	EMPI T2	6.98	7.54	0.20	1.15	0.70	0.90	1.00	1.40	0.20	0.90	0.35	0.34	0.78	1.91	0.01	0.02	1.49	2.43
	EMPI T3	7.80	7.83	0.60	1.00	2.40	4.50	1.40	2.80	0.80	2.40	0.28	1.35	1.17	2.52	0.02	0.06	1.60	1.84
Farm 5	QRY T1	7.50	7.29	0.20	0.35	0.90	0.70	1.30	1.00	1.60	1.90	0.81	1.01	0.48	0.87	0.04	0.05	0.44	0.72
	QRY T2	7.52	7.05	0.20	0.30	0.10	0.60	1.20	1.20	2.00	0.10	1.08	0.58	0.52	0.78	0.05	0.00	0.42	1.34
	QRY T3	7.02	7.15	0.30	0.40	0.90	0.80	1.20	1.30	1.80	0.90	0.95	1.25	0.70	0.96	0.05	0.02	0.59	0.92
Farm 6	EXCEL T1	7.01	7.04	0.30	0.35	0.80	1.00	1.00	1.30	1.20	1.05	0.41	0.49	0.57	0.91	0.03	0.03	0.63	1.04
	EXCEL T2	7.26	5.96	0.20	0.45	0.90	0.80	1.00	1.30	0.55	1.25	0.54	0.66	0.61	1.04	0.01	0.03	0.82	1.07
	EXCEL T3	7.00	6.38	0.45	0.30	1.10	0.60	2.10	1.40	1.90	1.10	0.15	0.94	0.78	0.78	0.04	0.03	0.77	0.77

Appendix 4: Harvested Rain Water in Greenhouse 1

Date	Rainfall depth (m)	Projected roof catchment area in meter square	Expected ideal volume to be harvested (m^3)	Ditch height (m)	Ditch height reading (m) after every rainfall event	Actual volume Harvested (m3)	Actual Volume harvested after every rainfall event(m^3)	Runoff coefficient=Ratio of Actual and Expected volume collected	Volume units per 1mm of rainfall	Volume (m^3) per 1mm of rainfall on $1m^3$ of surface area
24/10/2013	0.008	188.52	1.50816	0.24	0.24	1.0752	1.075	0.712789094	134.375	0.7127891
28/10/2013	0.001	188.52	0.18852	0.27	0.03	1.2258	0.1506	0.798854233	150.6	0.7988542
04/11/2013	0.012	188.52	2.26224	0.63	0.36	3.3138	2.088	0.922978994	174	0.922979
05/11/2013	0.0052	188.52	0.980304	0.756	0.126	4.167072	0.853272	0.870415708	164.09077	0.8704157
10/11/2013	0.002	188.52	0.37704	0.806	0.05	4.523272	0.3562	0.94472735	178.1	0.9447273
11/11/2013	0.012	188.52	2.26224	1.116	0.31	6.954912	2.43164	1.074881533	202.63667	1.0748815
30/11/2013	0.009	188.52	1.69668	1.296	0.18	8.543232	1.58832	0.936134097	176.48	0.9361341
01/12/2013	0.0078	188.52	1.470456	1.31	0.014	8.6722	0.128968	0.087706127	16.534359	0.0877061
08/12/2013	0.0026	188.52	0.490152	1.388	0.078	9.405088	0.732888	1.495225971	281.88	1.495226
14/12/2013	0.012	188.52	2.26224	1.548	0.16	10.984608	1.57952	0.698210623	131.62667	0.6982106
15/12/2013	0.0122	188.52	2.299944	1.814	0.266	13.837192	2.852584	1.240284111	233.81836	1.2402841

Appendix 5: Rain Water Harvesting Volume Greenhouse 2

Date	Rainfall depth (m)	Projected roof catchment area in meter square	Expected ideal volume to be harvested (m3)	Ditch height (m)	Ditch height reading (m) after every rainfall event	Actual volume Harvested (m3)	Actual Volume harvested after every rainfall event(m3)	Runoff coefficient=Ratio of Actual and Expected volume collected	Volume units per 1mm of rainfall	Volume (m3) per 1mm of rainfall on 1m3 of surface area
24/10/2013	0.007	540.424	3.782968	0.5	0.5	2.5	3.12	0.824749245	445.7143	0.824749
04/10/2013	0.01	540.424	5.40424	1.15	0.65	7.245	4.745	0.8780143	474.5	0.878014
05/11/2013	0.0055	540.424	2.972332	1.4	0.25	9.52	2.275	0.765392291	413.6364	0.765392
09/11/2013	0.004	540.424	2.161696	1.55	0.15	11.005	1.485	0.686960609	371.25	0.686961
11/11/2013	0.007	540.424	3.782968	1.75	0.2	13.125	2.12	0.560406538	302.8571	0.560407
27/11/2013	0.002	540.424	1.080848	1.8	0.05	13.68	0.555	0.513485708	277.5	0.513486
28/11/2013	0.0015	540.424	0.810636	1.85	0.05	14.245	0.565	0.696983603	376.6667	0.696984
30/11/2013	0.012	540.424	6.485088	2.2	0.35	18.48	4.235	0.653036628	352.9167	0.653037
01/12/2013	0.006	540.424	3.242544	2.38	0.18	20.8488	2.3688	0.730537504	394.8	0.730538
02/12/2013	0.0045	540.424	2.431908	2.5	0.12	22.5	1.6512	0.678973053	366.9333	0.678973
09/12/2013	0.019	540.424	10.268056	2.95	0.45	29.205	6.705	0.652996049	352.8947	0.652996
10/12/2013	0.009	540.424	4.863816	3.2	0.25	33.28	4.075	0.837819523	452.7778	0.83782
11/12/2013	0.018	540.424	9.727632	3.6	0.4	40.32	7.04	0.723711588	391.1111	0.723712
12/12/2013	0.03	540.424	16.21272	4.2	0.6	52.08	11.76	0.725356387	392	0.725356
14/12/2013	0.013	540.424	7.025512	4.4	0.2	56.32	4.24	0.603514733	326.1538	0.603515
15/12/2013	0.023	540.424	12.429752	4.9	0.5	67.62	11.3	0.909109047	491.3043	0.909109

Appendix 6: Water Harvesting Volume Greenhouse 3

Date	Rainfall depth (m)	Projected roof catchment area in meter square	Expected ideal volume to be harvested (m3)	Ditch height (m)	Ditch height reading (m) after every rainfall event	Actual volume Harvested (m3)	Actual Volume harvested after every rainfall event(m3)	Runoff coefficient=Ratio of Actual and Expected volume collected	Volume units per 1mm of rainfall	Volume (m3) per 1mm of rainfall on 1m3 of surface area
27/9//2013	0.0061	188.52	1.149972	0.16	0.13	0.6912	0.6912	0.601058113	113.3114754	0.601058113
01/11/2013	0.0024	188.52	0.452448	0.25	0.09	1.125	0.4338	0.958784214	180.75	0.958784214
06/11/2013	0.0058	188.52	1.093416	0.335	0.085	1.56445	0.43945	0.401905588	75.76724138	0.401905588
07/11/2013	0.0028	188.52	0.527856	0.435	0.1	2.11845	0.554	1.049528659	197.8571429	1.049528659
08/11/2013	0.0082	188.52	1.545864	0.636	0.301	3.352992	1.234542	0.79860971	150.5539024	0.79860971
09/11/2013	0.0101	188.52	1.904052	0.848	0.212	4.830208	1.477216	0.775827551	146.2590099	0.775827551
10/11/2013	0.0015	188.52	0.28278	0.995	0.147	5.96005	1.129842	3.995480586	753.228	3.995480586
20/11/2013	0.0042	188.52	0.791784	1.057	0.062	6.462498	0.502448	0.634577107	119.6304762	0.634577107
22/11/2013	0.006	188.52	1.13112	1.161	0.104	7.339842	0.877344	0.775641842	146.224	0.775641842
29/11/2013	0.0005	188.52	0.09426	1.17	0.009	7.4178	0.077958	0.827052833	155.916	0.827052833
02/12/2013	0.006	188.52	1.13112	1.26	0.09	8.2152	0.7974	0.70496499	132.9	0.70496499
06/12/2013	0.0136	188.52	2.563872	1.53	0.27	10.8018	2.5866	1.008864717	190.1911765	1.008864717
08/12/2013	0.0181	188.52	3.412212	1.756	0.226	13.191072	2.389272	0.700212062	132.0039779	0.700212062
10/12/2013	0.0338	188.52	6.371976	2.2	0.444	18.48	5.288928	0.830029492	156.4771598	0.830029492
12/12/2013	0.0358	188.52	6.749016	2.625	0.425	24.28125	5.80125	0.859569751	162.0460894	0.859569751
14/12/2013	0.0155	188.52	2.92206	2.725	0.1	25.75125	1.47	0.503069752	94.83870968	0.503069752
15/12/2013	0.088	188.52	16.58976	3.528	0.803	39.005568	13.254318	0.798945735	150.61725	0.798945735