UTILIZATION OF RAINWATER HARVESTING TECHNOLOGIES AMONG SMALLHOLDER FARMERS IN MURANG'A COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented elsewhere for a degree or any other award.

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DEDICATION

I dedicate this work to my parents Mrs. Ruth Wanjiru Runo and Mr. Jimnah Itemo Irungu for their support. I also dedicate this work to Mr. David Thiga Mwangi and his family in California, United States of America (USA) for his immense support provided throughout my academic journey specifically, for his sponsorship back in Kiaguthu Boys High School in Murang'a County and for his continued financial support and mentorship up to my Masters level.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ACRONYMS AND ABBREVIATIONS

ADP	Annual Development Plan
ANOVA	Analysis of Variance
ASL	Above Sea Level
BETA	Bottom-up Economic Transformation Agenda
CGDP	County Government Development Programs
CIDP	County Integrated Development Plan
CSA	Climate Smart Agriculture
EAC	East African Community
GAPs	Good Agricultural Practices
GIS	Geographic Information Systems
Ha	Hectares
IAFPS	Integrated Agricultural Farming Production Systems
IDT	Innovation Diffusion Theory
IPCC	Intergovernmental Panel on Climate Change
KNBS	Kenya National Bureau of Statistics
KSHs	Kenyan Shillings
MoALF	Ministry of Agriculture, Livestock and Fisheries
NARIGP	National Agricultural and Rural Inclusive Growth Project
NGO	Non-Governmental Organization
RWH	Rainwater Harvesting
RWHM	Rainwater Harvesting and Management
RWHT	Rainwater Harvesting Technology
RWHTs	Rainwater Harvesting Technologies
SD	Standard Deviation
SDGs	Sustainable Development Goals
SPSS	Statistical Package for Social Sciences
SRWHTs	Surface Rainwater Harvesting Technologies
SSA	Sub-Saharan Africa
UM	Upper Midland
UN	United Nations

USA	United States of America
USD	United States Dollars
UTaNRMP	Upper Tana Natural Resources Management Project
WH	Water Harvesting
WHT	Water Harvesting Technology

DEFINITION OF TERMS

Ex-situ technologies	Systems that capture rain water (RW) away from the storage point (Samdani & Arora, 2011)
Household	A group of people living and eating their meals in the same dwelling of a particular region (Chianu & Tsujii, 2004).
In-situ technologies	Technologies that adopt soil management strategies with an aim to reduce runoff on the soil surface and increase water infiltration (Samdani & Arora, 2011)
Rainwater harvesting	A technique in collection, inducing, storing and conservation of rainwater for productive purposes (Pachpute *et al*. 2009)
Smallholder farmer	One who owns/rents a land less than or equal to 2 Ha in size and is largely dependent on labor from the family members and choose a production enterprises that meet his/her household food security and maintains cash flow (Joshi *et al.*, 2006)
Water harvesting technology	Is a technique used in collection and storage of or rainwater from roads, rock catchments, buildings or land surfaces (Galván *et al*., 2018)

ABSTRACT

Water is a critical resource in environmental sustainability, agricultural production as well as for improved livelihoods. Climate variability hinders crop and livestock production in Sub-Saharan African countries. Rainwater harvesting (RWH) is a climate smart agricultural practice to revert this. Rainwater harvesting has been practiced among smallholder farmers for centuries in many parts of the world. Recently, it has gained more attention due to the reported increasing water demand and the need for sustainable water management hence the research was conducted to evaluate the utilization of rainwater harvesting technologies (RWHTs) as a climate smart agricultural practice in Murang'a County, Kenya. Drawing on data from a cross sectional survey of 384 households, our research evaluated the adoption of RWHTs, intensity of crop and livestock enterprises adoption under RWHTs and the determinants for RWH among smallholder farmers in Murang'a County, Kenya. Multistage random sampling and proportionate to size technique was employed to sample farmers in three wards namely: Murarandia, Mugoiri and Wangu. The KOBO kit a phone application was used during data collection. To assess the adoption of RWHTs, descriptive statistics and analysis of variance (ANOVA) were applied. The results found that rooftop water harvesting technology ($93^a \pm 22$), infiltration pits ($81^a \pm 21$), furrows ($68^a \pm 16$), deep ploughing ($67^a \pm 21$), terraces ($54^a \pm 14$), mulching ($51^a \pm 17$), retention ditches ($23^a \pm 18$) and water pans ($17^a \pm 5$) water harvesting technologies had statitistical significant differences among smallholder farmers ($P<0.05$), while negarims, water bunds and dams water harvesting technologies were not statistically significant ($P<0.05$) adopted at a mean ± S.D of 11 ± 4, 6 ± 2 and, 1 ± 1 smallholder farmers, respectively. The findings exhibited that households that practiced livestock production including: dairy cattle farming, goat rearing, sheep farming, beef cattle rearing, pig production, and poultry farming, watered their livestock using rooftop harvested rainwater at a rate of 12%, 10%, 9%, 6%, 3% and 5%, respectively while, 1% practiced aquaculture. Multivariate probit model (MVP) analysis showed that crop enterprises adopted (macadamia, maize, coffee, tea, avocado, fodder, arrowroots, beans, bananas, mangoes and sweet potatoes) among household heads were key crop enterprises that influenced adoption of these RWHTs. The MVP model also pointed out that household head's access to credit facilities, landownership, age, level of income, education level, gender, family size, source of income, membership to farmers' groups and access to training services were statistical significant ($P<0.05$) thus, influenced RWH adoption. Membership to farmers group had merits including: support in farmers' training, social ties, source of information and source of credit which were also key determinants to RWH adoption. The study recommends relevant stakeholders and policy makers to consider promotion or up scaling of RWHTs for crop and livestock enterprises among household heads in consideration of the determinants influencing adoption rate in Murang'a County.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water scarcity across the globe has been attributed partly due to climate change that has led to variable rainfall patterns and the ever increasing population that has raised water demand (Gosling & Arnell, 2016; He *et al*., 2021). Similarly, water resources are generally not uniformly distributed thus scarce in some areas (Baguma *et al.*, 2010). Fresh water constitutes 2.5% of the global total water resources (Ray & Chowdhury, 2012), accounting for less than 0.01% of the total water resources since 30% of the total fresh-water is in liquid form while 80% of this is unavailable. An average rate of 1300 m^3 cap^{-1} per year is required for food production for a healthy diet (Rost *et al.*, 2009), making water a precious resource for development of agricultural economy (He *et al.*, 2021; Motho *et al.*, 2022). There has been increasing water demands not only for agricultural purposes but also for industrial and household functions (IPCC, 2023). This has increased issues related to freshwater quality and quantity across different regions in the world thus accelerated water scarcity levels which is also the case in Kenya (IPCC, 2023; Murgor *et al.*, 2013; Ndahi & Maitho, 2017). It has been projected that, by 2025 two third of the global population will experience water scarcity (Norman *et al*., 2019). This has triggered immediate attention on sustainable water supply among households in rural areas (Baguma *et al.*, 2010).

According to World Bank (2016), Kenya's agricultural productivity as well as Gross Domestic Product (GDP) has been on a decline due to climate change vulnerability and large dependence on rain-fed agriculture which stands at between 16 to 18%. Poor water management practices, unreliable and unpredictable rainfall patterns and low soil fertility are contributing factors that threaten agricultural production among smallholder farmers (Muchai *et al*., 2020). Water shortages exacerbated by climate change impact negatively on livestock productivity (Lutta *et al.,* 2020). In Kenya, climate related shocks have negatively impacted on different farm enterprises (Gichangi & Gatheru, 2018). Smallholder Kenyan farmers are expected to face more challenges due to increased varying and changing climatic conditions (Hisali *et al*., 2011) including reduced agricultural yields (Junaidu *et al.,* 2017). Sub-Saharan Africa (SSA) receives a highly erratic rainfall that normally falls with high intensity as intense storms at temporal and spatial variability (Bitok *et al.*, 2023; Ngure *et al*., 2021; Timothy *et al*., 2022). This has led to increased necessity for storm water management (Edwards *et al*., 2016).

Smallholder farmers in SSA depend on rain-fed agriculture despite seasonal dry spells arising from poor rainfall distribution and variability (Muriu-Ng'ang'a *et al.*, 2017). Furthermore, Teklewold *et al*. (2017) noted that smallholder farmers in SSA have limited capacities for adaptation, building resilience, coping, and recovering from climate shocks associated with unpredictable rainfall patterns. Inadequate rainwater management strategies has led to low agricultural productivity in SSA (Muchai *et al.*, 2020). However, it is necessary to enhance improved agricultural water management to sustain the crucial current agricultural production patterns (Akroush *et al.*, 2016; Binyam & Desale, 2015) and increase production to meet the food and feed demand to the increasingly population in SSA.

Rainwater harvesting (RWH) is a good approach towards climate resilience and adaptation in SSA (Odhiambo *et al*., 2021, Odhiambo *et al*., 2022). Pachpute *et al*. (2009) noted that RWH helps in conservation of rainwater for productive purposes including livestock production (Giffoni *et al*., 2019), household domestic consumption, and crop production (Mzirai & Tumbo, 2010). Rainwater harvesting is a promising approach in supplementing both underground and surface scarce water resources in areas under higher water demand (Aladenola & Adeboye, 2010; Mzirai & Tumbo., 2010).

The practice of RWH involves collecting runoff from a catchment area (Lo & Gould, 2015) hence is an alternative source of water (Słyś & Stec, 2020) when common sources such as rivers and wells fail (Murgor *et al.*, 2013). This technology adopts runoff recycling and reuse approach to meet water demands (Sample & Liu, 2014). Increased runoff result from poor water management practices thus, land degradation in many smallholder farming systems (Chalise *et al.*, 2019). Increased runoff triggers low water infiltration rates in the soil reducing soil moisture available for crop production under rain-fed agricultural systems (Murgor *et al.*, 2013). It also causes increased soil erosion in most Kenyan landscapes and Counties such as Murang'a County (Kiroso, 2015).

Rainwater harvesting is one of the climate smart agricultural (CSA) practice practiced in Kenya including Murang'a County (Mwaura *et al*., 2018; Bitok *et al.*, 2023; Röhrig *et al.*, 2017; Maindi *et al.,* 2020). The key goals of the practice is to harness both groundwater and rainwater to enhance a more resilient agricultural production and increases adaptability and flexibility on site specific functions to fight water scarcity (FAO, 2015). Rainwater harvesting technologies contribute to increased agricultural productivity as well as increasing farm income among smallholder farmers in many developing countries (Zingiro *et al*., 2014). It enhances yield stability throughout the year as well as increased income among smallholder farmers (Totin *et al*., 2018). Interest in rainwater harvesting technologies (RWHTs) has thus been renewed in African countries including Ethiopia, Rwanda and Kenya (Hisali *et al*., 2011; Zingiro *et al.*, 2014*).*

About 16-18% of Kenya's landmass is suitable for rain-fed agriculture. In Kenya, government and development agencies support on-farm adaptation technologies such as climate smart agricultural technologies (Maindi *et al.*, 2020; Mwaura *et al.*, 2018) such as RWHTs to cope with climate hazards that affect agricultural productivity (Lutta *et al.*, 2020). These hazards include floods, landslides and droughts as it is the case in Murang'a County (Maindi *et al*., 2020; Bitok *et al*. 2023). Ministry of Agriculture, Livestock and Fisheries (MoALF) identifies RWH as a long-term intervention to address food insecurity (Waweru, 2013). This contributes to sustainable development goal (SDG) two on reducing poverty levels in developing countries such as Kenya (Bunclark & Lankford, 2011).

Key determinants for RWH adoption among smallholder farmers include technical, institutional support, economic and social variables (Akroush *et al.*, 2016; Mpatane *et al.*, 2016; Recha *et al.,* 2015; Senkondo *et al.,* 2004; Zingiro *et al.*, 2014). In addition, Jan (2020), Mairura *et al.* (2021 and Musa *et al*. (2022) found out that socio-economic, social demographic, institutional, government policies and environmental conditions are key factors determining adoption of RWHTs. These factors determine the decision to adopt RWHTs (Lutta *et al*., 2020) at household levels hence the crop and livestock enterprises adopted differ. Rainwater harvesting involve micro-catchments including: pits such as *Zai* pits (Muchai *et al*., 2020), ridges such as tied ridges (Motsi *et al*., 2004), retention ditches, deep ploughing, and terracing for water storage in the plant root zone (Mzirai & Tumbo, 2010). Collection of runoff from a macro catchment using diversion systems for storage on surface reservoir (FAO, 2015), is also rain water harvesting. Broadly, RWHT include runoff/surface water harvesting (Rost *et al.*, 2009), subsurface water harvesting, roof water harvesting and flood water harvesting (Chowdhury *et al.*, 2012).

This study was limited to evaluating the roof water harvesting and runoff water harvesting technologies adopted in Murang'a County. The study assessed the crop and livestock enterprises practiced under the RWH technologies and the social and institutional factors influencing the adoption rate among smallholder farmers at household level.

1.2 Problem Statement

Murang'a County experiences rainfall variability and occasional extreme high temperatures resulting in increased water scarcity, prolonged droughts and drying of rivers contributing to unreliable agricultural production among smallholder farmers. Agricultural production among smallholder farmers in Murang'a County is dependent on the rainfall pattern. In addition, during long rains season, soil erosion in form of landslides resulting from increased rainwater runoff has been experienced in the county leading to declined arable land. In addition, areas in Kiharu Sub-County around Kairi, Githambo, Gitugi, Mioro, Kahuro and Inoi has experienced landslides intensively hence a constraint for both crop and livestock production (Bitok *et al.*, 2023). However, an alternative such as rainwater harvesting is one of the measures to increase water availability and reduce soil erosion from rainwater runoff among smallholder farming systems in the County. Rainwater harvesting technologies have been adopted in most African countries including Kenya to boost agricultural productivity (Kifle *et al.*, 2022; Timothy *et al.*, 2022). Past studies show that Murang'a County residents practice RWH as an alternative source of water among households (Mwangi *et al.*, 2020). According to the County's Annual Development Plan (ADP, 2019), projects have been initiated funded under the County government development programs on RWH among households under various crop and livestock enterprises. Research on RWH technologies adopted at household level in Murang'a County is scanty. Secondly, crop and livestock enterprises practiced in the County under RWH adoption have not been documented in past research. Thirdly, adoption of RWH technologies is influenced by several factors including: social-demographic and social-economic factors among others whose documentation in past research is scanty. This research study was a three-front approach to close these gaps by evaluating the adoption of RWH in Murang'a County. First, the study aimed to determine the RWH technologies adopted at household level. Second to evaluate the crop and livestock enterprises practiced under RWHT. Thirdly, to evaluate the socio-economic and socio-demographic factors influencing the rate and intensity of RWH adoption among smallholder farmers in Murang'a County, Kenya

1.3 Research Objectives

General objective

To evaluate the adoption and characterize rainwater harvesting technologies among smallholder farmers in Murang'a County, Kenya

Specific objectives

1. To determine the adoption of rainwater harvesting technologies by smallholder farmers in Murang'a County.
2. To evaluate the crop and livestock enterprises adopted under rainwater harvesting among smallholder farmers in Muranga County.
3. To examine the socio-economic, institutional and socio-demographic determinants influencing adoption of rainwater harvesting technologies among smallholder farmers in Murang'a County.

1.4 Research Questions

1. What are the rainwater harvesting technologies adopted by smallholder farmers in Murang'a County?
2. What are the crop and livestock enterprises practiced under rainwater harvesting among smallholder farmers in Murang'a County?
3. What are the socio-economic, institutional and socio-demographic factors influencing adoption of rainwater harvesting technologies among smallholder farmers in Murang'a County?

1.5 Justification

To achieve optimal and sustainable agricultural productivity among smallholder farmers in Murang'a County, there was need to evaluate the rate of RWH adoption and the social factors influencing adoption under different crop and livestock enterprises. Assessment of both crop and livestock enterprises adopted under different RWH technologies aimed to help the Ministry of Agriculture, Livestock and Fisheries in the County on agricultural development programs implementation. This is in partnership with other organizations such as National Agricultural and Rural Inclusive Growth Project (NARIGP) and Upper Tana Natural Resources and Management (UTaNRMP) in achieving one of the African's Agenda 2063 goal number six whose one of the main focus is conservation of existing water resources on improved Agriculture.

This research aimed at evaluating the agricultural enterprises adopted under RWHTs in Murang'a County. Increased productivity throughout the year due to sustainable water management through RWH aim to increase crop and livestock yields hence more income and improved livelihoods. The evaluation of RWHTs adoption showcased the different technologies utilized among smallholder farming systems in Murang'a County. This project also contributed in achieving one of the County's goals which is also a key goal to the East African Community's vision 2050 (CIDP, 2023) towards a more stable, developed and a competitive bloc through showcasing how to prudently utilize water resources as one of the natural resource under higher demands in the region. This research aimed to contribute to achieving thirteenth goal on United Nations SDG on climate action showcasing and identifying the gaps on RWHTs adoption as a climate smart agricultural technology. In addition, this research project further contributed to SDGs two, five, six and fifteen by infusing the innovation and RWHTs among smallholder farmers in Murang'a County thus contributing to increased sustainable agricultural production.

This contributes to the current government blueprint known as Bottom-up Economic Transformation Agenda (BETA) on increasing agricultural productivity and as one of the solutions to food insecurity and policy on climate change in Kenya. It also aimed at knowledge dissemination to the County's agricultural department on embracing the set project on enhanced water harvesting, storage and mega dams' construction by 2050. This research study also aimed to guide in agricultural and climate related policy making process on rainwater harvesting and management (RWHM) by the department of Agriculture in the County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter broadly discusses RWH adoption across the globe. It also describes the benefits of rainwater harvesting to climate change adaptation, rain-fed agriculture and irrigation. This was in conjunction with the crop and livestock enterprises adopted in different countries under RWH technologies. The chapter also focuses on the common socio-demographic and socio-economic factors influencing the adoption of different RWH technologies among smallholder farmers in different regions across the globe.

2.2 Rainwater Harvesting

Rainwater harvesting has been documented from the ancient Greek and German civilizations (Debusk, Kathy & Hunt 2014). A wide variety of RWHTs have been adopted globally (Samdani & Arora, 2011; Lo & Gould, 2015). Lo & Gould (2015) stated that RWHTs have been adopted for over 400 years at an increasing rate across the globe. Rainwater harvesting is commonly adopted in areas experiencing limited access to water resources (Debusk, Kathy & Hunt 2014; Motho *et al*., 2022) especially in arid and semi-arid lands (ASALs) of Middle-East, North America as well as Sub-Saharan Africa (Liu & Jin, 2017). Abdulla & Al-Shareef (2009) stated that RWH has been put into practice from the middle ages time through late 1900s in Jordan, India, some parts of Asia, South America and Europe especially in Italy.

The findings by Abdulla & Al-Shareef (2009) were similar to the findings of Joshua *et al.* (2012) and Kpadonou *et al.* (2017). Mendez *et al*. (2011) also pointed out that increased water supply shortages, climatic changes and rapid population growth rates in United States, China, Australia and Germany are the main contributing factors to RWHTs adoption as an alternative water supply in the regions. Adham *et al*. (2016a) and Lasage & Verburg (2015) also reported that RWHTs have been adopted to increase agricultural productivity in ASALs of Tunisia.

Rainwater is also harvested from other surfaces including: sidewalks, parking lots, paved surfaces and landscape areas (Debusk, Kathy & Hunt 2014). It has also been adopted in African countries (Ngigi, 2003a) including Ethiopia (Kifle *et al*., 2022), Malawi (Mangisoni, 2019), Uganda (Baguma *et al*., 2010; Aham *et al*., 2018), Kenya (Mwaura *et* *al*., 2018; Bitok *et al.*, 2023), Tanzania (Timothy *et al*., 2022), Burkina Faso, Rwanda (Zingiro *et al*., 2014), Ghana (Theis *et al.*, 2018), Nigeria (Nicholas & Ukoha, 2023), Botswana (Mpatane *et al*., 2016) and Zimbabwe (Mupangwa *et al*., 2006). However, given the differences in climate and socio-economic conditions, studies to assess location specific RWH adoption are important to identify the challenges and opportunities to improve the adoption. This study aimed to close this gap by evaluating the utilization of rainwater harvesting technologies among smallholder farmers in Murang'a County, Kenya.

2.2.1 Benefits of rainwater harvesting

Rainwater harvesting technologies are commonly used to achieve maximal accumulation and storage of rainwater through *ex-situ* and *in-situ* technologies (García-Ávila *et al*., 2023). Chowdhury *et al*. (2012) supported the adoption of both *in-situ* and *ex-situ* RWHTs. The systems are of great importance due to numerous socio and economic benefits (Odhiambo *et al*., 2022). These benefits include increased groundwater recharge and infiltration (Binyam & Desale, 2015) hence increased ecosystem services (Stout *et al*., 2015), providing irrigation water among smallholder farmers and reducing storm water discharge (Bitok *et al*., 2023; Edwards *et al*., 2016). Additionally, increased ingress in groundwater and in sea water at coastal areas, provision of drinking water for human and livestock consumption and reducing overloads in sewage treatment plants (Sample & Liu, 2014).

Mangisoni (2019) noted other reasons for RWH adoption in South Malawi including: provision of independent water supply during water restriction times hence is a social capital for urban water supply (Triyono *et al*., 2021), provision of water during drought periods, used to supplement main water supply systems, flood mitigation (Binyam & Desale, 2015) and reduction (Freni & Liuzzo, 2019) and increasing potable water availability (Christine *et a*l., 2017). The systems play a great role in watershed management serving as an incentive to ensuring protected water resources and woodlands (Samdani & Arora, 2011). Samdani & Arora (2011) and (Li, 2003) observed that RW collected from RWHTs is used for irrigated crop production. This helps in combating climate change through reduced water scarcity during droughts (Muñoz *et al*., 2019). In addition, RWH has been adopted in most developing countries as a strategy in poverty reduction among small-scale farmers across the globe (Bunclark & Lankford, 2011). The technology also plays a great role in landscape management, aesthetic values maintenance as well as in public and commercial water supply (Samdani & Arora, 2011). Further, WH system is a key driver to success of both farm-level and regional development programs in most countries. This systems also have economic benefits in SSA as well in Kenya (Mwaura *et al.*, 2018).

2.3 Rainwater Harvesting under Rain-Fed and Irrigated Agriculture

Globally, rain-fed agricultural land area is approximately at 80 % and generates 65 to 70 % of the staple foods to the population inhabiting the areas (Anantha *et al.*, 2021). However, Rao *et al.* (2014) stated that low and increasing production variability have been a menace whose adaptation is of great concern in most countries such as India. In addition, it is estimated that 275 million hectares of land is dedicated to irrigated crops which increase at a rate of 1.3% annually (Muñoz *et al*., 2019) thus placing agricultural ecosystems as the prepondent consumers of water resources at a global scale (Muñoz *et al*., 2019). Globally, increased demand for food production has resulted to increased water consumption (Muñoz *et al*., 2019). Since 1,300 m^3 cap^{-1} yr^{-1} of water is required for food production, water consumption rate is estimated to be greater than 8,000km^3 yr^{-1} on both irrigated and rain-fed land which feeds the present world population (Rost *et al.*, 2009). Rost *et al*. (2009) showed that an additional 5,000 km^3 per year of water is required to meet the demands of a population rising to about 10 billion by 2050. Li, (2003) noted that a RWH system has different technological components including RWH, production systems, and water saving irrigation systems. Similarly, water ponds are adopted in India as one of the RWHTs and the stored water is re-used for life saving crops in traditional farming systems like *Zabo* system, paddy cum fish and Bamboo drip irrigation under irrigation as well as utilization for domestic purposes (Chowdhury *et al*., 2012).

Sub-Saharan Africa's agricultural land supports 95% rain-fed agriculture which accounts for 35% continent's GDP (Benimana *et al*., 2015). However, increased inter- and intra-rainfall seasonal periods in Africa have resulted to frequent food shortages and livelihoods losses among poor smallholder farmers. Mangisoni (2019) suggested that RWH should be adopted in Southern Malawi to ensure that crop production was not affected due to the observed reduced irrigation practices in the region. Ngigi, (2003) stated that in SSA small-scale water harvesting systems is yet to be realized hence should be adopted to address temporal and spatial water scarcity for overall water resources management as an approach in agricultural water management in practices such as crop production, livestock development, environmental management and domestic purposes. Results from Rosegrant & Cai (2002) showed that there was an overall increased rain-fed agricultural production of the total production in SSA.

In Kenya, RWH have been adopted in shifting high dependence on rain-fed agriculture thus increased RWH for irrigation purposes among smallholder farmers as one of the technology in CSA. In Murang'a County, the irrigated land is estimated to be 1000 Ha with both food and cash crops (CIDP, 2018). According to CIDP (2023), the acreage under food crops is 329,234 acres which is almost twice that of cash crops which is 177,636 acres. Different livestock enterprises have also been adopted in the County including: dairy cattle, beef cattle, sheep, pigs, poultry and goats at a total population of 326,802, 39,681, 59,782, 63,074, 1,630,974 and 178,498 respectively, in the County (CIDP, 2023). Aquaculture has also been an emerging enterprise with a total of 2,146 fish farming families owning over 2,127 fish ponds by the year 2022. These enterprises have not been characterized in the past researches. This study aims to evaluate RWHTs adopted under rain-fed and irrigation agricultural practices among smallholder farmers in Murang'a County.

2.3.1 Agricultural enterprises practiced under RWH

Agriculture is one of the most important sectors in many Sub-Saharan Africa countries, where 60-70% of the rural livelihoods population in Tanzania depend on the agricultural enterprises (Pachpute *et al*., 2009). Rainwater harvesting is a method that aim to induce, collect, conserve and store local surface runoff mainly for agricultural production (Motsi *et al*., 2004). Chowdhury *et al*. (2012) noted that, water ponds and lakes are used in India for RWH in traditional farming systems for crop production as well as for fish production. Islam *et al*. (2017) conducted a research in Bangladesh, and found out that monsoonal RW increased cropping intensity from 155% to 300% for different crop and livestock enterprises grown in the region such as rice cultivation, fruit production, vegetable production and fish production. Similarly, Lupia *et al*. (2017) found that rooftop rainwater harvesting has a high potential in provision of a self-sufficient water supply system to residential gardens mainly for homegrown vegetables and fruits crop enterprises in urban areas of Rome, Italy. In semi-arid areas of China, water harvested under RWHTs is used for cash and food production (Li, 2003). Crops grown in China included wheat, corn, vegetables, tobacco, flowers, and fruits trees under irrigation. In addition, RWH can also be used in rearing of livestock and poultry farming (Li, 2003; Samdani & Arora, 2011).

Different RWHTs were introduced in Africa in the past which are still practiced today for agricultural production (Motsi *et al*., 2004). These countries include Swaziland, Zimbabwe, Ethiopia, Kenya (Motsi *et al*., 2004) and Botswana (Bunclark & Lankford 2011). These findings concur with Kayombo *et al*. (2004) who found 120-152% increased maize yields in Mwanga district, Tanzania using micro catchments. Pachpute *et al*. (2009) found out that the principal crops grown on average farm holdings in Tanzania are beans, vegetable and maize enterprises adopted under different RWH technologies. Lebel *et al*. (2015) evaluated the in-situ RWHT as an adaptation strategy to climate change for maize production projecting 14% to 50% increased yields by 2050. A research conducted in Bugesera district, Rwanda also found that RWH is a viable option for improved crop production (Benimana *et al*., 2015). In-situ and ex-situ RWH technologies are used in Ethiopia in addressing temporal and spatial water scarcity for agriculture and domestic consumption and increasing agricultural diversification among small-scale farmers (Binyam & Desale, 2015). Similarly, Botha *et al*. (2015) reported that infield RWH significantly affects maize yields in South Africa. Woyessa *et al.* (2006) and Mango *et al.* (2018) also found out that in-field RWH increased yields in South Africa for sunflower and maize production. In addition, rainwater harvesting technologies are used for livestock use and production in most rural areas as it is the case in most semi-arid regions worldwide such as in Brazil (Giffoni *et al*., 2019).

Similar results have been found within different Counties in Kenya where RWH technologies have been adopted for different crop and livestock enterprises (Kimani *et al*., 2015). In Murang’a County, about 7.6 % of the total households rely on rainwater harvesting as the main source of water (KNBS, 2019b). However, there are no past researches that characterize crop and livestock enterprises adopted under RWHT among smallholder farmers in Murang'a County, Kenya.

2.4 Factors Influencing Adoption of Rainwater Harvesting Technologies

Adoption of RWHT is dependent on different social, cultural, climatic and economic factors (Muñoz *et al*., 2019). Research demonstrates a significant association between socio-demographic attributes at households levels to RWH technology adoption by farmers as presented in this section *(*Lutta *et al.*, 2020). Teklehaimanot & Besha (2003), Ngango & Hong (2021) and Siraj & Beyene (2017) also found that institutional and technical factors influence RWHT adoption. However, there are scanty research studies on the socio-economic, institutional and socio-demographic factors affecting RWH adoption. Socio-economic considerations have been a measure to evaluate the influence of both macro and micro catchment RWHTs adoption in Kenya (Recha *et al*., 2015; Kimani *et al*., 2015).

Studies show that education level of the farmers determines RWHTs adoption (Musa *et al.*, 2022). Akroush *et al.* (2016) indicated that educated farmers in Muharib and Majidya communities from Jordan ASALs adopted RWHTs more than non-educated farmers. Similarly, Neupane *et al*. (2002); Murgor *et al.* (2013); Shikur & Tesfaye. (2011) and Mekonnen (2017) reported that educated farmers are likely to adopt RWHTs than non-educated farmers as they easily accessed and interpreted relevant new information. Indigenous knowledge of a farmer is one of the consideration beside education level during knowledge-based decision making process on RWHTs adoption (Mbilinyi *et al*., 2005). Siraj & Beyene (2017) found that education levels determined RWHT adoption in Gursum District, Ethiopia. Lutta *et al.* (2020) also found out that household head's formal education among agro-pastoralists in South Eastern Kenya had a positive effect on RWHTs adoption which enhanced skills in water management and utilization in the ASALs. The results found by Lutta *et al.* (2020) and by this study concur with research done by Diro *et al*. (2022), Tesfaye (2017), Kimani *et al*. (2015), Akter & Ahmed, (2015) and Recha *et al.* (2015).

Access to credit by smallholder farmers in Murang'a County is a determining factor for adoption in modern agricultural enterprises (Wamunyu *et al*., 2017). Akroush *et al*. (2016) found that credit access by poor farmers exerted a positive effect on RWHT adoption. Similar results were reported by Lutta *et al.* (2020) and Murgor *et al.* (2013) in Kenya. Research conducted by Deressa *et al*. (2009) demonstrated that credit access to farmers had a positive significant association to RWH adoption. Lutta *et al*. (2020) reported access to extension services by agro-pastoralists in South Eastern Kenya ASALs significantly affected adoption of water harvesting structures (WHS). These results collaborates those by Khalid *et al*. (2017) and Akroush *et al*. (2016) which showed that access to extension services had a positive influence on farmers' adoption of RWH technologies. Mekonnen (2017) found that access to information from extension agents also influenced RWH adoption to famers in Ethiopia. Similar results were reported by (Shikur & Tesfaye, 2011) in Ethiopia. These results of this research study were in agreement with those of Siraj & Beyene, (2017**)** and Lutta *et al*. (2020) in Ethiopia and southern Eastern Kenya.

Inadequate access to land is a major constraint affecting adoption of technology such as RWH in most countries (Mekonnen, 2017). Land ownership or tenure systems also influence adoption of RWH as reported by Staddon *et al*. (2018). The findings of the present study collaborates with Kpadonou *et al*. (2017) and Mangisoni (2019) who pointed out that smallholder farmers who owned their land with title deeds adopted more water conservation technologies on their farms in West African Sahel and Southern Malawi, respectively. This is attributed to security of tenure providing security and motivating farmers to implement long term measures for crop improvement on their land like RWHTs.

Lutta *et al*. (2020), Khalid *et al*. (2017) and Ndiritu *et al*. (2011). Mekonnen (2017); Ahamada (2018); Gebregziabher *et al*. (2013) and Akroush *et al*. (2016) found that age of the household heads determined the adoption of RWHTs as it determined farmer's ability to respond to unforeseen shocks such as water shortages. They found out that older household heads adopted RWHTs than middle aged and young farmers. This was also found to be true in Burkina Faso in a research assessing adoption of *Zai* pits as a soil and water conservation technique (Sidibe, 2005). These results concur with the findings of Jan (2020) who found that older people adopted new RWHTs in ASALs of Pakistan more than young farmers. However this was contrary to the results of Belachew *et al*. (2020) who reported that increase in age of smallholder farmers negatively influenced adoption of RWHTs in Ethiopia. The differences in adoption of RWHTs in different age groups in different regions could be attributed to differences in te average age of farming households in different regions.

Wamunyu *et al*. (2017) reported that Murang'a County has more than 500 farmer's groups and cooperatives which influenced adoption of agricultural technologies. Kimani *et al*. (2015) also found that membership to community focus groups influenced RWHTs adoption by smallholder farmers in Makueni County. Similar results to this study were found by Lutta *et al*. (2020); Ahamada (2018) **;** Reza *et al*. (2018) and Muchai *et al*. (2020) that were done in South Eastern Kenya, Uganda, Indonesia and Eastern Kenya, respectively reporting that smallholder farmers who were members of farmer's group(s) were more likely adopt RWHTs**.**

Household size influences the adoption of RWHTs differently. Previous results showed that household size insignificantly affected RWHTs adoption among smallholder farmers in Tharaka-Nithi County, Kenya (Recha *et al*., 2015). The results of the present study are similar to the findings of Musa *et al*. (2022) and Siraj & Beyene, (2017) who reported increase in adoption of RWHTs with increase in household size in Western Kenya and Ethiopia, respectively. However, these results were contrary to the results found by Andati *et al.* (2022) who reported a decrease in adoption of RWHTs with increase in household size among potato smallholder farmers in Kenya. These differences were due to the different geographical locations and variability in climatic conditions in the regions. The differences may also be due to the different roles played by household members in establishing RWHTs in different geographical regions.

Mekonnen (2017) found that there are gender-specific constraints that directly affected technology adoption such as RWH technology in Ethiopia. He further stated that sex of the household head in relation to his/her education level determines RWHTs adoption. This concurs with the results of Shikur & Tesfaye (2011) and Murgor *et al*. (2013). The present study evaluated the institutional factors, socio-economic and socio-demographic determinants that influenced adoption of different water harvesting technologies in the study area.

2.5 Summarized Gap from Related Literature

From the past research, RWHTs have been adopted across the globe including in Kenya in the recent past. Different research focuses on both micro and macro catchment RWHTs. Factors including technical, institutional, economic and environmental have been researched on. The past studies have been conducted among the smallholder farmers in other Counties in Kenya but limited research in Murang'a County. However, there is scanty research conducted in Murang'a County on evaluating the adoption of RWHTs and characterization of RWHTs among smallholder farmers. In addition, there was scanty research conducted on evaluating the socio-economic, institutional and socio-demographic factors influencing RWHTs adoption by smallholder farmers in Murang'a County. Considering differences in geographic and socio-economics in different environments, research in specific areas is required to provide recommendation that can be applied in a specific area. This is especially critical since Agriculture and water management are devolved functions in Kenya, thus requiring County specific data to inform policy making. To contribute to this, the study assessed adoption of RWHTs, characterize the technologies based on farming practices or enterprises adopted and socioeconomic, institutional and demographic determinants for adoption in Murang'a County, Kenya.

2.6 Conceptual framework on adoption of RWHTs in Murang'a County

The figure below show the conceptual framework used for this study. Increased climate change such as high rainfall variability is the major cause for water scarcity in Murang'a County. These factors contribute to reduced agricultural production. To avert this, different RWHTs have been adopted to increase rainwater capture used for different crop and livestock enterprises in the County. The key determinants including the institutional factors, socio-economic factors and socio-demographic factors influenced the adoption of RWHTs which also influenced the adoption of different livestock and crop enterprises among smallholder farmers in Murang'a County.

Water shortage due to increased rainfall variability **(Problem)**

⇩

Adoption of rainwater harvesting technologies: rooftop water harvesting, terraces, infiltration pits, mulching, water pans, retention ditches, Water bunds, deep ploughing, furrows, negarims and dams ***(Objective 1- dependent variable)***

⇩ ⇩

Socio-economic, socio-demographic & institutional factors on adoption of RWHTs (*Objective 3- independent variables)*

Socio-economic

- Land ownership
- Farmer's group membership
- Training on RWHTs
- Sources and levels of income
- Information access on RWH

Socio-demographic

- Age
- Gender
- Household size
- Distance to source of water
- Education level

Institutional

- Sacco
- Microfinance
- Farmer's groups

Crops and livestock enterprises under water harvesting technologies *(Objective 2- independent variables)*

Crop enterprises

- Maize
- Macadamia
- Tea
- Coffee
- Fodder
- Avocado
- Arrowroot
- Bananas
- Beans
- Mangos
- Sweet potatoes
- Cabbage
- Tomatoes
- Kales
- Spinach

Livestock enterprise

- Goats
- Dairy cattle
- Beef cattle
- Sheep
- Pigs
- Poultry
- Aquaculture

Figure 2.1: Conceptual framework Source: own conceptualization

2.7 Theoretical Framework

Most researchers across the world have proposed several theoretical models on adoption of climate smart technologies such as RWHTs with an aim to adapt to climatic changes and increase agricultural production at farm level (Bitok *et al*., 2023). One of the proposed theories to explain adoption of RWHTs as a CSA practice in this research study is the Innovation Diffusion theory (IDT). Wani & Ali (2015) described IDT as a theory that assists a researcher in understanding the adoption rate of different innovations in a social system for a specified target population at particular time dimension. This theory was introduced in 1962 and later fine-tuned in 1995 (Wani & Ali, 2015). This theory explains how an idea or a technology is perceived among smallholder farmers in Murang'a County based on their knowledge of utilizing a technology, attitude towards RWHTs adoption, the decision to either reject or adopt the technology and finally to the implementation of the technology at a farm level.

In addition, Mujeyi *et al.* (2021) found that most of the models and theories based on adoption-perception, have some econometric constraints such as labor, credit access, land availability, sources and levels of income which may influence the adoption rate of a technology in Zimbabwe. Due to this, the IDT was used to determine the utilization of RWHTs in this research study considering these econometric constraints focusing on their empirical significant differences. This theory was also used by Bitok *et al*. (2023) to explain the determinants influencing adoption as well as the extent and awareness of the CSA technologies such as irrigation, ridges, intercropping, minimum tillage, crop rotation, drought tolerant livestock breeds, forage conservation and agroforestry among households in Murang'a amidst climate stress experienced in the year 2023. Therefore, this theory was fit for this research study to determine how smallholder farmers in Murang'a County utilized different RWHTs, how farmers adopted crop and livestock enterprises under the different RWHTs and also to determine the institutional, socio-demographic and socio-economic factors that influenced the adoption of RWHTs.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Overview

This chapter focused on describing the study area in Kiharu Sub County, Murang'a County, Kenya with detailed information on its location, population, climatic conditions, predominant soil type and the common agricultural practices. The section has also broadly discussed the target population, sampling procedure, research design, data collection, analysis of data and the models specifications used for data analysis based on the three research objectives.

3.2 Study Area

The study was carried out in Murang'a County, Central parts of Kenya as shown in Figure 3.1 below. Figure 3.1 was designed using Arc GIS software version 10.3. Murang'a County covers a land area of 2524.2 Square kilometers (KNBS, 2019a). It is located at a longitude of 36^{o} 37^{o} 27'E and between a latitude of 0^{o} 34' and 10^{o} 7'S (CIDP, 2023).

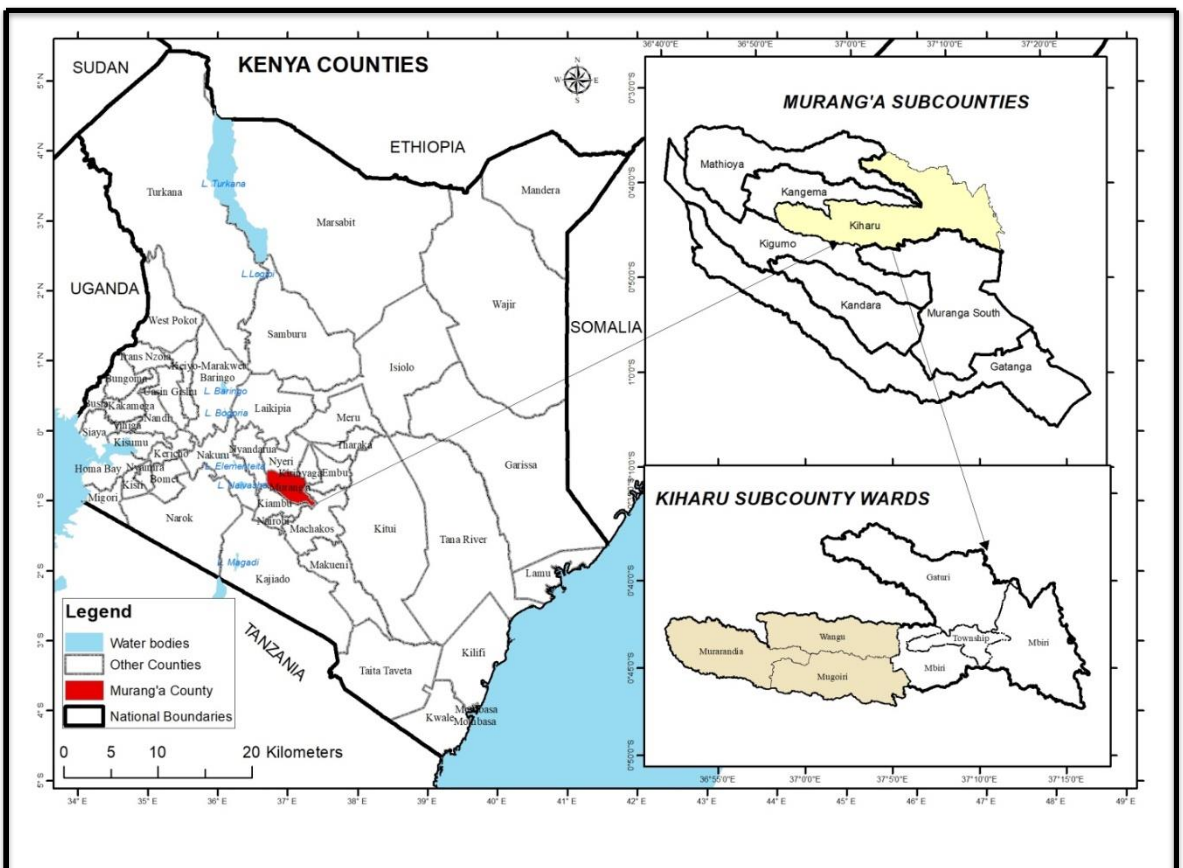

Figure 3.1: Study Location Map Source: Own conceptualization

It has a bimodal rainfall distribution experiencing both long rains and short rain between mid-March to the end of May and from October to December, respectively (GoK, 2006). However, Murang'a County has different soil types depending on the underlying geologic conditions of both basement system of rocks and volcanic rocks (Ovuka & Lindqvist, 2016). The predominant soils in the County are characterized by a dusky red to reddish-brown in color, extremely deep, well drained with a Humic topsoil and a friable clay hence are Humic Nitisols (Kalungu *et al*., 2013). The County receives an annual rainfall ranging between 1400 mm and 1600 mm. The County's temperature varies with altitude. The maximum annual temperature ranges in between 26^{o} C and 30^{o}C while the mean annual temperature conditions ranges between 14^{o} C and 18^{o} C (CIDP, 2023).

The main agricultural activity in the County is mixed farming. The County lies between altitudes of 914 m above sea level (ASL) from the east and 3353 m ASL from the west along slopes of Aberdare Mountain (Maindi *et al.,* 2020). According to the CIDP (2023) and Maindi *et al.* (2020) both food crops, cash crops and horticultural crops are grown in the area at 80% among the residents as well as livestock production. They include maize, bananas, macadamia, tea, potatoes, kales, cabbages, avocados, coffee and improved pastures (Maindi *et al*., 2020). As a result, agriculture greatly anchors County's economy (Maindi *et al*., 2020; CIDP, 2018).

Kiharu Sub-County was purposively selected as the study area in the County. This is because RWH projects such as water pans are implemented in the sub-County under funded projects by County government development programs (CDPs) in partnership with funded projects such as National Agricultural and Rural Inclusive Growth Projects (NARIGP) by the world Bank and Upper Tana Natural Resources and Management (UTaNRMP) by the International Fund for Agricultural Development. Kiharu is located in Murang'a East with three administrative wards namely: Murarandia, Mugoiri and Weithaga. Physiographic conditions vary from steep slopes to gentle slopes. It is located in the central region of the County with sub-tropical climatic conditions. The area has a combination of agro-ecological zones ; UM1, UM2, UM3 & UM4 (CIDP, 2023; GoK, 2006). There has been reported cases of water shortages due to climate shocks in the Sub-County hence the County government has been implementing RWHTs in the area (ADP, 2019). The area has Humic Nitisols as the predominant soils (Sombroek *et al.*, 1982). It has a population of 88,183 with 26,930 households (KNBS, 2019a). Kiharu Sub County covers an area of 169.4Km^2 (KNBS, 2019a).

3.3 Research Design

To determine the RWHTs and the crop and livestock enterprises in adoption under the RWHTs, the study employed a cross-sectional survey. The survey was conducted through on-farm face to face interview done to the targeted households in all the three wards. Two administrative locations from each ward were identified and one sub-location from each administrative location was randomly sampled. This was a one-time data collection exercise conducted by four trained enumerators from the study area.

3.4 Sampling Design

Multistage sampling technique was employed to select households included in the research study. Kiharu Sub-County was purposively sampled in the first stage as there has been rainwater harvesting projects funded by both governmental and non-governmental organizations (NGOs). The second stage employed stratified sampling where the sample frame population was grouped into three administrative wards (Table 3.1). The third stage was a random sampling of two administrative locations from each ward. The last stage employed random sampling of households from one sub-location per each administrative location proportionate to the total sample size and administrative ward sample size.

The sample size was calculated using Cochran's formula (Bartlett *et al.*, 2001) as shown below:

$n_0 = \frac{z^2 pq}{e^2}$ …………. (*Equation 1*)

Where: n= sample size, p= percentage picking of a choice (for example 1.96 for 95% level of confidence), z= z value, q= 1-p and e= the allowable error

A sample size of 384 households was obtained using the formula below:

$n_0 = \frac{(1.96^2)(0.50)(0.50)}{(0.50^2)}$

= 384 household heads

Proportionate sample size distribution was done and tabulated in Table 3.1 below after obtaining a sample frame from Kiharu Sub-County Agricultural Offices:

Table 3.1: Household sample size for Kiharu Sub-County on RWHTs

Ward	Target HH	Sample size	Administrative location	Target HH	Sample size	Sub-location	Target HH	Sample size
Mugoiri	9, 347	133	Githagara	2, 337	62	Mirichu	875	62
			Kiria	2, 662	71	Kiria	930	71
Murarandia	8, 898	127	Gatuya	1, 524	62	Kianjogu	645	62
			Kaganda	1, 592	65	Thengeini	669	65
Weithaga	8, 685	124	Wanjengi	1,880	51	Wanjengi	1279	51
			Weithaga	2, 655	73	Kianderi	707	73
Total	26,930	384			384			384

3.5 Data collection

Data collection was based on a questionnaire (Appendix 1) that combined closed and open ended questions which was administered at household level and recorded by enumerators using Kobo collect software. Data was collected from all the three wards namely; Mugoiri, Murarandia and Wangu. Pre-testing of the questionnaire was done in Kagaa location in Mugoiri ward, Thengeini location in Murarandia ward and Kahuhia location in Wangu ward and the data collected proofed the applicability and reliability for the targeted data collection exercise using a Kobo collect software. This also helped in Kobo collect app kit testing prior to data collection exercise which resulted to a smooth data collection exercise in the targeted administrative locations per ward.

The interview was administered with the help of four enumerators who were recruited prior to the data collection exercise and trained on how to use the mobile data collection toolkit. The interviews were conducted at household's level. During the interview, household heads were interviewed but in their absence a phone call was made by the enumerator to conduct the interview or the most senior member of the household was requested to assist the enumerator to fill in the questionnaire. The interview focused on both social-economic factors such as access to credit access, access to extension services, education level and source of income and social-demographic factors such as: household size, land ownership, land slope, household head age and household gender to determine their influence on adoption to different crops and livestock enterprises under RWHTs in Kiharu Sub-County, Murang'a County.

3.6 Data Analysis

The collected data was organized and cleaned in excel data sheet and exported for analysis using Statistical Package for Social Sciences (SPSS) version 25 and STATA version 14.1 software. Descriptive statistics was used to determine the utilization of RWHTs as well as the crop and livestock enterprises practiced under the different RWHTs. Cross tabulations and frequencies obtained from the analysis was used to develop the relationships between the various factors of RWHTs adoption.

3.6.1 Models specifications

Objective 1

Descriptive statistics including frequency, mean and standard deviation was used to determine the utilization of the selected rain water harvesting technologies among smallholder farmers in Murang'a County. Furthermore, a one way Analysis of Variance (ANOVA) was conducted to test the variations between the utilized technologies. The F-value tested the significance with the values equal to or less than 5% of the P-value.

Objective 2: Crop and livestock enterprises adopted under rainwater harvesting technologies

A multivariate probit model was used to analyze this objective as recommended by Kpadonou *et al*. (2017), Musa *et al*. (2022) and Okello *et al*. (2021). This model is the most appropriate because different RWHTs influenced by farm enterprises adopted by a household head were simultaneously evaluated and allowed the error terms to correlate. Since the study was based on more than two RWHTs, a household may select one or more technologies for different farm enterprises due to different unknown and unobservable characteristics of the household heads to be sampled and their farms. Therefore, this model was appropriate to avoid statistical biasedness and inefficiency in estimation. The dependent variables were the RWHTs while the independent variables were the crops enterprises.

This model is as expressed in equation two below:

$Y_{ij} = X_{ij} \beta_{ij} + \varepsilon_{ij}$ ………………..*(Equation 2)*

Where;

Y_{ij} represents various rainwater harvesting technologies adopted by farmers among households i is the household id (1, 2, 3, 4…384 households)

j is the type of technologies (terraces, mulching, water bunds, negarims, water pans, retention ditches, infiltration pits, furrows, rooftop RWH and deep ploughing)

x is the vector of the predictor variables (the crop and livestock enterprises)

β is the vector of parameters to be estimated to predict the model

ε is the normally distributed unobserved error term

In reference to utility maximization theory, household may adopt RWHTs if the benefits outweigh the household who have not adopted the RWHTs. Normally, this is presented as a dichotomous observable outcome for each water harvesting technology adopted by smallholder farmers or household heads. This can be represented in the equation three below:

Y_{ij}=1 if Y_{ij}……….. *(Equation 3)* where j= T, Ip, M, N, D, Wp, Wb, F, Rd, Dp

0 otherwise

Where, Y_{ij} is an observable binary variable for a smallholder farmer to adopt a j^{th} water harvesting technology by an i^{th} farmer. Where RWHTs adoption is assumed to co-occur for different smallholder farmers a variance co-variance matrix is used to describe error terms as shown in the equation four. The δ represents a pairwise correlation relationship for a combination of any two RWHTs with a negative sign showing a complement in the relationship and a positive sign shows the significant relationship

Objective 3: Socio-economic, institutional and socio-demographic factors influencing adoption of rainwater harvesting technologies

Characteristics of the sampled farmers in Murang'a County were subjected to ANOVA to test the significance of the characteristics. Additionally, the same model Multivariate Probit Model (MVP) was used to determine socio-demographic, socio-economic and institutional factors on credit access that influenced adoption of various RWHTs in Murang'a County. Both RWHTs and the determinants were simultaneously evaluated and allowed the error terms to correlate hence the model was fit to analyze this objective. The RWHTs were dependent variables while the determinants i.e. socio-economic, socio-demographic and institutional factors on credit access were the independent variables. The X variables on multivariate probit model were different for objective two representing the determinants for RWHTs adoption (age, gender, and education level, distance to source of water, sources and levels of income, training access to RWHTs, membership to farmers' groups, information access and sources of credit access among households in Murang'a County).

3.7 Description of Variables Used in the Model for this Research Study

In this section, the variables (RWHTs, determinants for adoption of RWHTs and the enterprises adopted under RWHTs) used were defined and explanations done on how they were measured as shown in Table 3.2 below.

Table 3.2 : Description of variables used in the model for this research study

Variables	Type of variable	Description and measurement
RWHTs		
Rooftop WHT	Dummy	Household head use of rooftop WHT {0=yes; 1=no}
Terraces	Dummy	Household head use of terraces {0=yes; 1=no}
Infiltration pits	Dummy	Household head use of infiltration pits {0=yes; 1=no}
Mulching	Dummy	Household head use of mulching {0=yes; 1=no}
Negarims	Dummy	Household head use of negarims {0=yes; 1=no}
Furrows	Dummy	Household head use of furrows {0=yes; 1=no}
Retention ditches	Dummy	Household head use of retention ditches {0=yes; 1=no}
Water pans	Dummy	Household head use of water pan {0=yes; 1=no}
Dam	Dummy	Household head use of dam {0=yes; 1=no}
Water bunds	Dummy	Household head use of water bunds {0=yes; 1=no}
Deep ploughing	Dummy	Household head use of deep ploughing {0=yes; 1=no}
Socio-demographic		
Gender	Dummy	Gender of the household head {1=female; 2=male}
Age	Continuous	Age of the household head in years
Household size	Continuous	Number of family members dependent on household head
Education level	Dummy	If the household head attended any formal education {0=yes; 1=no}
Distance to source of water	Continuous	Household head's accessibility of water sources in kilometers
Socio-economic		

Farmer's group membership	Dummy	Household head was a member of farmer's group {0=yes; 1=no}
Training on RWH adoption	Dummy	If household head had attended any training on adoption of RWHTs {0=yes; 1=no}
Source of income	Dummy	If a household head accessed credit either from pension, farming, casual labour, business or salary {0=yes; 1=no)
Land ownership	Dummy	Household head who owned land with a title deed or leasehold terms {0=yes; 1=no}
Information access	Dummy	If households accessed information {0=yes; 1=no}
Institutional factors		
Access to credit	Dummy	If household accessed credit either from saccos, banks, microfinance and farmer's group {0=yes; 1=no}
Crop enterprises		
Maize	Dummy	Household head practiced maize farming under RWHT {0=yes; 1=no}
Macadamia	Dummy	Household head practiced macadamia farming under RWHT {0=yes; 1=no}
Coffee	Dummy	Household head practiced coffee farming under RWHT {0=yes; 1=no}
Tea	Dummy	Household head practiced tea farming under RWHT {0=yes; 1=no}
Avocado	Dummy	Household head practiced avocado farming under RWHT {0=yes; 1=no}
Fodder	Dummy	Household head practiced fodder farming under RWHT {0=yes; 1=no}
Arrowroots	Dummy	Household head practiced arrowroots farming under RWHT {0=yes; 1=no}
Sweet potatoes	Dummy	Household head practiced sweet potato farming under RWHT {0=yes; 1=no}
Bananas	Dummy	Household head practiced banana farming under RWHT {0=yes; 1=no}
Beans	Dummy	Household head practiced beans farming under RWHT {0=yes; 1=no}
Mango	Dummy	Household head practiced mango farming under RWHT {0=yes; 1=no}

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Chapter Overview

This chapter has presented and discussed the characteristics of the sampled households and results of the three research objectives. On the first objective, the RWHTs adopted in Murang'a County were presented and discussed followed by the crop and livestock enterprises adopted among smallholder farmers under RWHTs and lastly the results of the third objective on examining the institutional, socio-economic and socio-demographic determinants for RWHTs in Murang'a County.

4.2 Characteristics of RWHTs adopters in Kiharu Sub County, Murang'a County

The study interviewed 384 household heads. This section has discussed the socio-demographic, socio economic and institutional characteristics of RWHTs adopters in Kiharu Sub-County, Murang'a County.

4.2.1 Socio-demographic characteristics of RWH adopters in Murang'a County

4.2.1.1 Gender

The sampled HH constituted 71% male while 29% were female. This means that male-headed households in Murang'a County highly adopted RWHTs compared to female-headed households. This could be due to the presence of more male headed households in Kiharu Sub County. This findings agreed with the findings of Kpadonou *et al*. (2017) in Burkina Faso and Bitok *et al.* (2023) in the same Sub County as that of the present study.

4.2.1.2 Age of the household heads

Most of the HH (40%) interviewed ranged between 46-60 years old, 30% ranged between 36-45 years old, 20% were above 60 years old while only 11% were youths ranging between 18-35 years old as shown in Figure 4.1 below. This showed that most of RWH adopters ranged between 46-60 years and 36-45 years in Kiharu Sub County. These findings collaborates with the results found by Bitok *et al*. (2023) who stated that smallholder farmers who highly adopted climate smart technologies in Kiharu ranged between the two age groups due to more experience, skills, exposure and more energetic to adopt agricultural technologies in the region. However, most youths and the aged did not adopt these technologies in Kiharu Sub County.

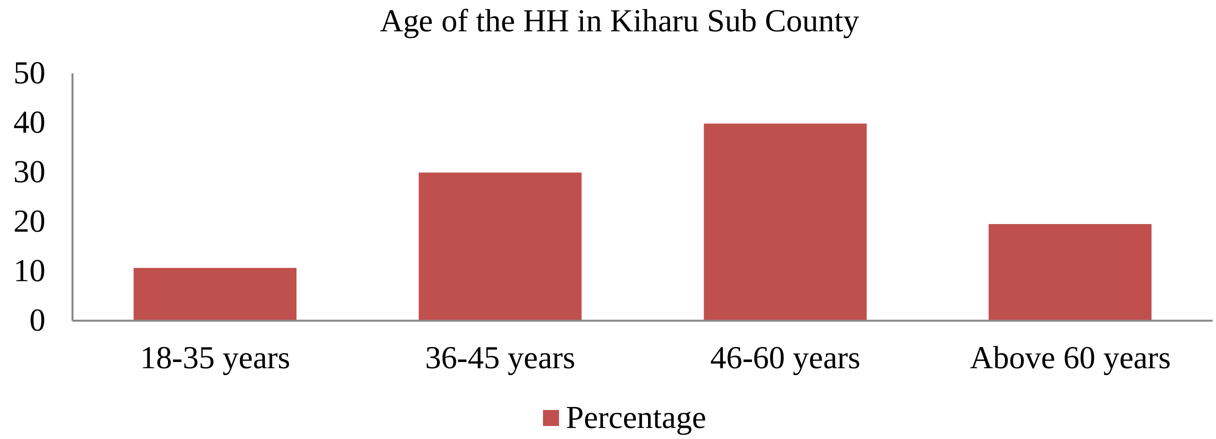

Figure 4.1: Age of the household heads in Kiharu Sub County, Murang'a County

4.2.1.3 Education level of the household heads

Most of the HH interviewed were educated with the least educated having attended a primary school. 48% of the HH attended up to a primary level, 38% had a highest education level at a secondary level while only 8% had attended a tertiary institution as shown in Figure 4.2. However, the rest were illiterate. The HH who were illiterate had at one household member who helped in decision making on adoption of RWHTs. This showed that most of the HH had at least attended a primary school and thus likely to adopt a RWHT in Kiharu Sub County. These results are similar to the findings of Bitok *et al.* (2023) who stated that most of the smallholder farmers in Kiharu Sub County had attended a primary school and highly intensified CSA technologies.

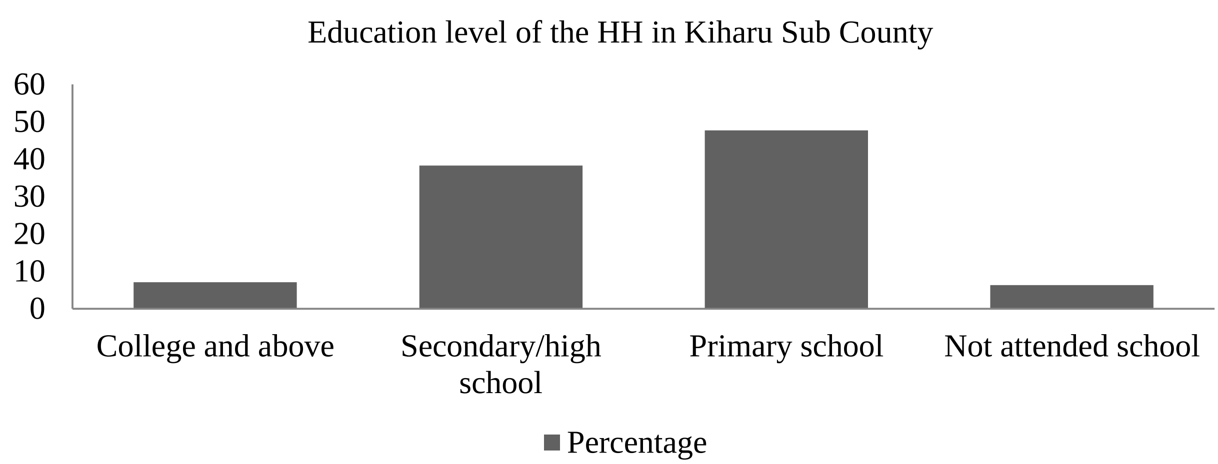

Figure 4.2: Education of the household heads in Kiharu Sub County, Murang'a County

4.2.1.4 Size of the households

Most of the households had a household size ranging between one to five household members at 36% while 32% of the households had six to ten members and 33% of the households had more than ten members as shown in Figure 4.3. This revealed that households with between one to five members highly adopted RWHTs in this region as compared to households with between six members and above.

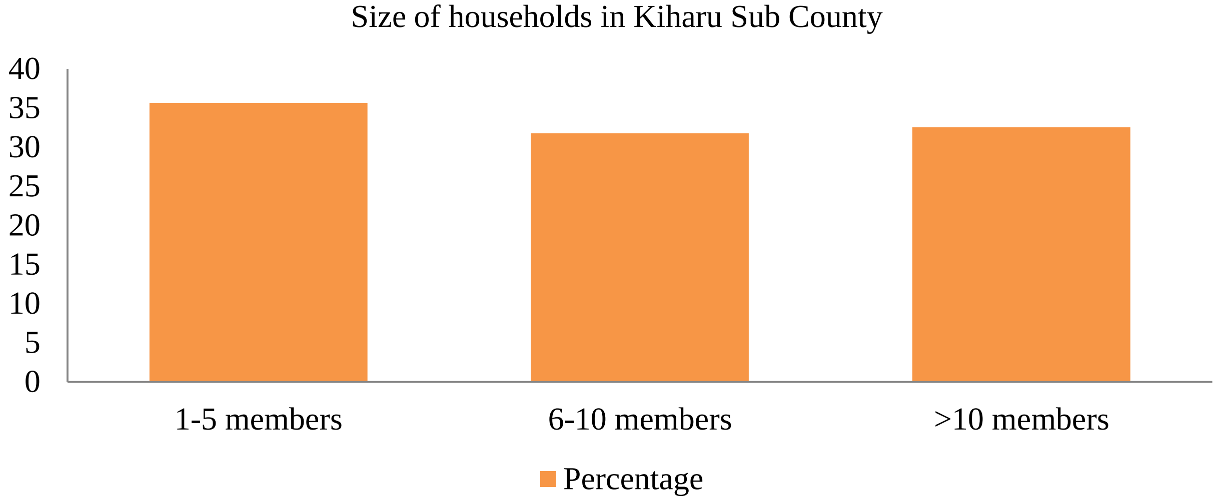

Figure 4.3: Size of the households in Kiharu Sub County, Murang'a County

4.2.2 Socio-economic characteristics of RWH adopters in Kiharu Sub-County, Murang'a County

4.2.2.1 Land ownership

Most of the household heads had more secured land with title deeds at 90% while the rest had leased lands at 10%. Some had more than one pieces of land with title deeds and some had several pieces of leased lands situated at different geographical locations of the study area away from their household.

4.2.2.2 Sources and levels of income among household heads

Table 4.1 showed that HH who relied on farming (51±4), business (35±5), casual labor (41±5) and salary (13±3) as their main sources of income were statistically ($P \leq 0.05$) significant (Table 4.1). This further showed that the HH whose main source of income was casual labor in Murang'a County were more likely to adopt water harvesting technologies as compared to HH who relied on business, salary, pension and farming. In addition, pension had no statistical significance difference in comparison to other sources of income ($P<0.05$). This suggested that HH who relied on pension were least likely to adopt RWHTs (7±3).

Table 4.1 : ANOVA table showing main sources of income among smallholder farmers in Murang'a County

Source	Mean ± S.D	F-value	P-value
Businesspersons	$35^{a} \pm 5$	13.731	0.002
Farming	$51^{a} \pm 4$	55.990	0.000
Pension	7 ± 3	3.673	0.094
Casual labor	$41^{a} \pm 5$	44.321	0.000
Salaried	$13^{a} \pm 3$	7.062	0.005

Root MSE = 0.3179, R-squared = 0.1342, Adj R-squared = 0.1251, Superscripts [a], indicated significance at 5%

Classification of HH on levels of income is as shown in Figure 4.4 below. Levels of income varied widely among HH in Kiharu Sub-County. Most of the HH were casual laborers at 63%. Out of these, more than half (60%) of HH who relied on casual labor earned below Kenya Shillings ten thousand, 3% earned between Kenyan Shillings ten thousand and fifty thousand per month while, none of them earned above fifty thousand Kenyan Shillings per month. Based on the four levels of income as per the World Bank (2023) rating residents in Kiharu Sub-County can be categorized as low middle income as most of them were casual laborers who earned below Kenyan shillings fifteen thousand per month.

Farming was ranked second as a main source of income among HH in Murang'a County at 51%. Most of the farmers interviewed had adopted different crop and livestock enterprises. Out of the 51% who relied on farming as their source of income earned below Kenyan shillings ten thousand (37%), 13% earned between Kenyan shillings ten thousand to fifty thousand per month while, only 1% earned between Kenyan shillings fifty thousand to one hundred thousand per month. None of the interviewed farmers earned above one hundred thousand Kenyan shillings per month under farming as the main source of income.

Business was ranked third as a main source of income in Murang'a County at 34%. Household heads who earned their income from owned business varied based on their scale of business and success. Out of these 34 % HH, 14% earned less than ten thousand Kenyan shillings per month, 17% earned between Kenyan shillings ten thousand and fifty thousand per month, 2 % earn between Kenyan shillings fifty thousand and one to Kenyan shillings one hundred thousand per month while, only 1% earned above one hundred thousand Kenyan shillings per month as businesspersons.

Salary was the fourth ranked source of income in Murang'a County. The research study found that only 13% of the HH were employed and relied on their salary as a source of income. Out of 13% employed HH, 1% earned above one hundred thousand Kenyan shillings per month, 1% earned between Kenyan shillings fifty thousand and one to one hundred thousand Kenyan shillings per month, 8% of the HH earned between Kenyan shillings ten thousand and fifty thousand per month while, only 1% earned below ten thousand Kenyan shillings per month. Pension was also one of the main sources of income ranked as the least relied main source of income among HH in Murang'a County at 7%. Out of 7% of the HH who relied on pension, 5% earned below ten thousand Kenya shillings per month, only 1% earned between ten thousand and fifty thousand Kenya shillings per month. Lastly, only one percent of the HH earned above fifty thousand Kenya shillings per month. This reveals that residents in Murang'a County were low middle income earners agreeing with the report of WorldBank, (2023) on world countries ranking and lending groups which ranked Kenya as a low middle income earning country.

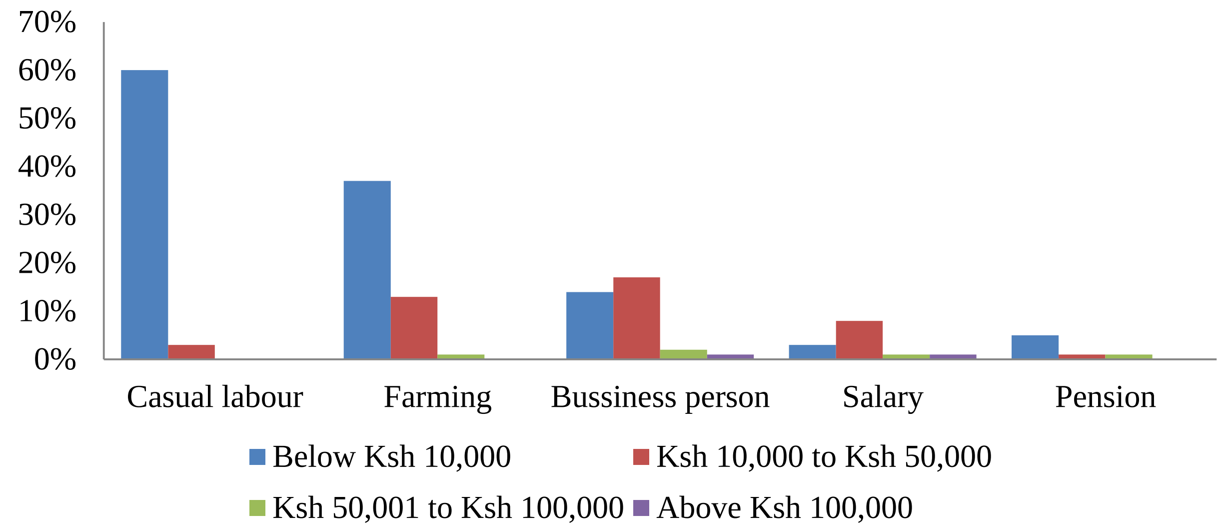

Figure 4.4 : Levels of income among household heads in Kiharu Sub County, Murang'a County

4.2.2.3 Access to training and farmers' group membership

Most of the HH had no access to training services for adoption of RWHTs in Murang'a County. However, only 37% had access to training on RWHTs. Most of them stated that they obtained trainings from farmers' groups, Sub County extension officers and non-governmental organizations fostering RWHTs in the study area. This revealed the likelihood of farmers in Murang'a County to adopt RWHTs. Only a few (25%) of the HH were members of at least one farmers' group who benefited differently. This means that most of the HH interviewed were non-members to farmers' groups in Murang'a County. This was similar to the results of Bitok *et al*. (2023) in Kiharu Sub County who found that smallholder farmers were trained from farmer's groups, by extension agents and NGOs on adoption of CSA practices.

4.2.2.4 Information access among household heads

In addition, only a few of the HH had access to information from various sources. Table 4.2 showed that farmers who accessed information from farmer's groups, agricultural shows, NGOs and extension agents on adoption of RWHTs had a positive statistical ($P \leq 0.05$) significance. This positively influenced the increased adoption of RWHTs in the county. These results agree with the results of Bitok *et al.* (2023) and Musa *et al.* (2022) who found that farmers in Kiharu Sub county and Western Kenya obtain information on CSA technologies from Extension agents, farmer's groups, NGOs and agricultural shows.

In addition, these results agreed with the findings of Gikunda *et al.(*2021) who found that extension officers as a source of information influenced the adoption of CSA practices in Mbeere North Sub County, Kenya. However, there was no statistical (P≤0.05) difference on farmers who accessed information from friends and relatives (P<0.05) as their main source of information on adoption of RWHTs. These results differ with the findings of Anantha *et al.* (2021) who found that smallholder farmers relied on friends as their sources of information on adoption RWHTs as a CSA practice in Southern Asia. These differences could be due to cultural differences in the different communities.

Table 4.2: ANOVA table showing the main sources of information among HH in Murang'a County

Source	Mean ± S.D	F-value	P-value
Friends/relatives	2 ± 1	1.326	0.238
Farmer's group	3^{a} ± 2	9.937	0.003
NGO	1^{a} ± 1	5.208	0.045
Extension agents	5^{a} ± 2	13.308	0.002
Agricultural shows	11^{a} ± 5	25.878	0.000

Superscript [a] indicated significance at 5%, Number of observations = 384, R-squared = 0.3367, Root MSE = 0.1776, Adj R-squared = 0.3314

4.2.3 Institutional characteristics

The principal institutional factors in this study were farmers' groups, SACCOS, banks and microfinance which were the main sources of credit to most of the HH in Kiharu Sub County. Banks, SACCOs and microfinances were statistically significant (P≤0.05). The study found that most of the farmers relied on SACCOs (30±5) as their main source of credit for RWH adoption with least relying on farmer's groups (6±2). However, credit access from farmer's groups was not statistically (P≤0.05) significant (Table 4.3). This showed that most of the HH were non-members of the credit institutions to finance their water harvesting projects in their households. The findings of this study are comparable to the results found by Bitok *et al*. (2023) and Ngango & Hong (2021) who found out that smallholder farmers who highly adopted RWHTs in Murang'a County, Kenya and Rwanda, respectively were members of credit institutions.

Table 4.3: Institutional characteristics among HH in Murang'a County

Source	Mean ± S.D	F-value	Prob>F
Sacco	30 [a] ± 5	91.694	0.000
Microfinance	15 [a] ± 4	24.3883	0.001
Farmers' group	6 ± 2	0.9991	0.326
Banks	11[a] ± 3	10.0043	0.003

Superscript [a] indicated significance at 5%, number of observations = 384, Root MSE = 0.2864, Adj R-squared = 0.1422, R-squared = 0.1490

4.3 Rainwater Harvesting Adoption in Kiharu Sub County, Murang'a County

This study found diverse adoption of RWHTs among HH in the study area. Surface RWH and rooftop water harvesting were the principal technologies commonly adopted in Murang'a County at 88% and 93%, respectively. In addition, some of the HH in Kiharu Sub-County relied on other main sources of water such as river, piped water, borehole, wells, dams and storm water. These findings were similar to the results of Belachew *et al*. (2020) who found that dams were adopted as one of the physical soil and water conservations structures in Ethiopia. Additionally, These results agree with the county's CIDP (2023) report which reported that wells, rain, boreholes, rivers and piped water are the main sources of water among households in Murang'a County. Piped water and rivers as main sources of water were statistically ($P \leq 0.05$) significant. This showed that most of the HH relied on piped water and rivers as their main source of water at household level (76[a] ±29, and 14[a] ±7 respectively). However, some households relied on other water sources that were insignificant ($P<0.05$) including boreholes, storm water, dam and wells at an average mean of 7±3, 3±2, 1±1 and 2±1, respectively. These findings agreed with the results of Maindi *et al.* (2020) who found that smallholder dairy farmers in Murang'a County had piped water, boreholes and tanks to harvest rainwater utilized for feeding their animals.

Table 4.4: ANOVA table showing main sources of water among HH in Kiharu Sub-County, Murang'a County

Source	Mean ± S.D	F-value	P-value
River	14[a] ± 7	3.630	0.004
Piped water	76[a] ± 29	10.851	0.001
Borehole	7 ± 3	1.118	0.178

Dam	1 ± 1	0.150	0.695
Rain	3 ± 2	1.733	0.194
Well	2 ± 1	0.931	0.349

Superscript [a] indicated significance at 5%,

The surface rainwater harvesting technologies were differently adopted by smallholder farmers in Murang'a County. This could be due to differences in establishment and maintenance costs, the cost of labor and their ease of use among smallholder farmers (Bitok *et al*., 2023). Further this research study found that technologies adopted in Murang'a had significant ($P \leq 0.05$) differences thus were adopted differently. Infiltration pits were statistically significant ($P \leq 0.05$). Infiltration pits technology was the most highly adopted type of SRWHT among household heads in this region at an average mean of 81 ± 21. Furrows and deep ploughing were statistically ($P \leq 0.05$) significant and adopted by an average mean of 68[a] ± 16 and 67[a] ± 21 of the smallholder farmers, respectively. In addition, terraces, mulching, retention ditches and water pans were statistically ($P \leq 0.05$) significant with about 54±14, 51±17, 23±18 and 17±5 average means of smallholder farmers who utilized these technologies, respectively. However, water bunds, negarims and dams were not statistically ($P \leq 0.05$) significant. This revealed that dams (1 ± 1), water bunds (6 ± 2) and negarims (11 ± 4) were least adopted in comparison to other RWHTs These results agree with the findings of Bitok *et al*. (2023) and Musa *et al.* (2022) who found that terracing, furrowing, zai pits, mulching are CSA technologies adopted in Kiharu Sub-county and Kenya at large.

Table 4.5: Mean adoption of rainwater harvesting technologies among smallholder farmers in Murang'a County

RWHT	Mean ± S.D	F-value	P- value
Rooftop technology (0=yes)	93[a] ± 22	63.793	0.000
Surface RWHTs (0=yes)	88 ± 19		
Infiltration pits (0=yes)	81[a] ± 21	59.517	0.000
Furrows (0=yes)	68[a] ± 16	46.077	0.000
Deep ploughing (0=yes)	67[a] ± 21	45.313	0.000
Terraces (0=yes)	54[a] ± 14	48.832	0.001
Mulching (0=yes)	51[a] ± 17	32.113	0.003

Retention ditches(0=yes)	23[a] ± 18	8.078	0.004
Water pans (0=yes)	17[a] ± 5	7.472	0.009
Negarims (0=yes)	11 ± 4	6.670	0.753
Water bunds (0=yes)	6 ± 2	3.031	0.481
Dams (0=yes)	1 ± 1	0.000	0.997

Superscript [a] indicate statistical significance at 5%

Rainwater harvesting technologies were adopted for various reasons which included: crop production, domestic purposes and livestock production while some, adopted for a combination of the three stated reasons at 86%, 73%, 26% and 20% respectively as shown in Figure 4.5 below. This study agree with the results of Bitok *et al.* (2023) who found that CSA technologies have been adopted in Murang'a County for livestock and crop management technologies and innovations.

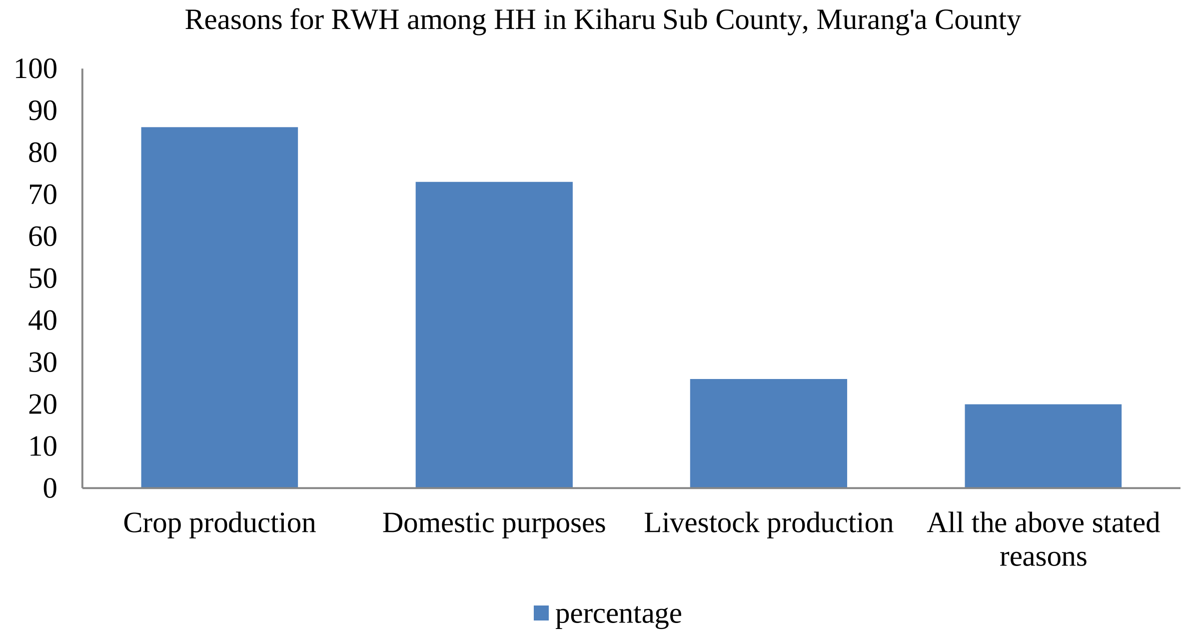

Figure 4.5: Reasons for adoption of RWH among HH in Kiharu Sub County, Murang'a County

Table 4.6 show that there was significant differences between the storage facilities used harvested rainwater (P≤0.05). Rainwater harvesting adopters used different water storage facilities including water tanks, water pans, jerry cans and drums. Water tanks were highly utilized to harvest storm water (78[a] ±4) smallholder farmers while, water pans were least utilized by an average mean of 19[a] ±3 smallholder farmers to harvest rainwater in Murang'a County. Most of the HH in this region harvested and stored rainwater which was later utilized in irrigation of crops as well as livestock production. These results concur with the findings of Andati *et al*. (2022); Kpadonou *et al*. (2017); Maindi *et al*. (2020); Musa *et al*. (2022) and Ondieki *et al*. (2019) done in Nyandarua County, Kenya., West African Sahel., Murang'a County, Kenya., Western Kenya and Kisii County, Kenya respectively.

Table 4.6: Storage facilities for rooftop harvested water in Murang'a County

Source	Mean ± S.D	F-value	P-value
Water tanks	$78^{a} \pm 4$	84.523	0.000
Jerry cans	$51^{a} \pm 5$	18.045	0.001
Water pans	$19^{a} \pm 3$	3.734	0.044
Drums	$26^{a} \pm 4$	5.788	0.025

Number of observations = 384, R-squared = 0.1480, Adj R-squared = 0.1480, Root MSE = 0.3819, Superscript ^{a}, indicated significance at $p<0.05$

Figure 4.6 tabulates the utilization of the principal WHT per ward. In comparison, rooftop technology was highly adopted in Mugoiri ward at 37% followed by Murarandia ward at 33% and least adopted at 30% in Wangu ward. Household heads highly adopted SRWHT in Mugoiri and Wangu wards at 35% and least adopted in Murarandia ward at 30%. Moreover, some HH intensified the two technologies in combination at 35%, 33% and 32% in Wangu, Mugoiri and Murarandia wards, respectively.

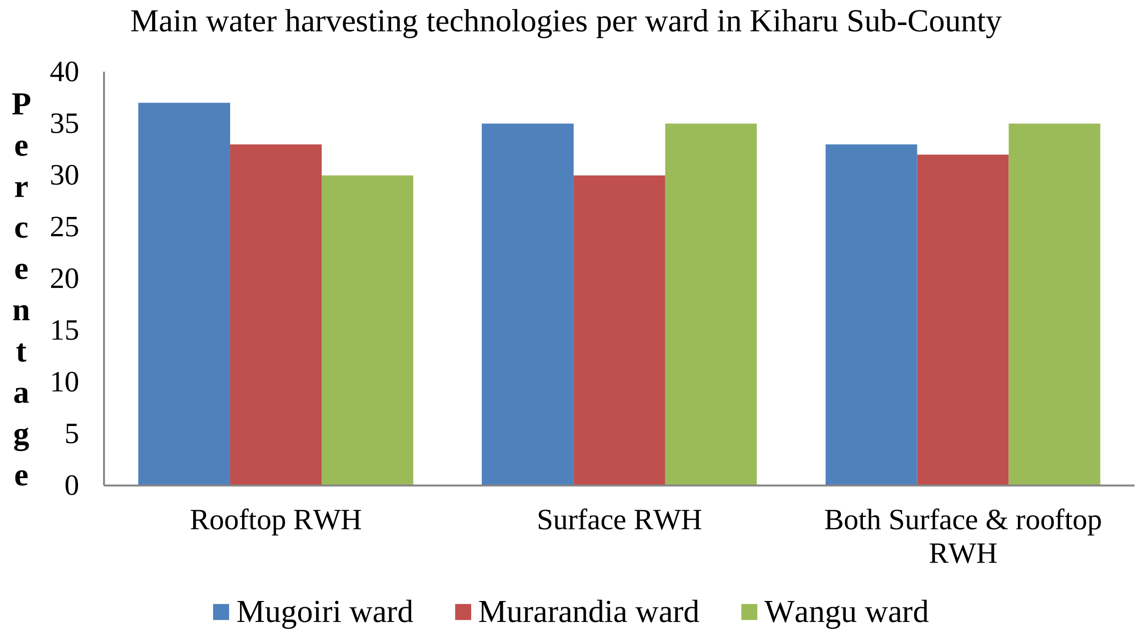

Figure 4.6: Principal water harvesting technologies per ward in Kiharu Sub County in Murang'a

4.4 Adoption of surface rainwater harvesting technologies per ward in Kiharu Sub-County

Table 4.7 below tabulates the respective frequencies and percentages of surface water harvesting technologies intensification per ward in Murang'a County.

Table 4.7: Adoption of surface rainwater harvesting technologies per ward in Kiharu

SRWHT	Mugoiri (n=133)	Murarandia (n=127)	Wangu (n=124)
		adopters	
Terrace	64(48)	76(60)	68(55)
Infiltration pits	103(77)	112(88)	94(75)
Mulching	68(51)	60(47)	67(54)
Negarims	17(13)	11(9)	15(12)
Dam	1(1)	-	-
Water pan	48(36)	8(6)	11(9)
Water bunds	11(8)	2(2)	8(6)
Furrows	81(61)	88(69)	91(73)
Retention ditches	29(22)	26(20)	33(27)

Deep ploughing	91(68)	88(69)	80(65)

Values inside parentheses represents the percentage while those outside parentheses showed the frequency

In Mugoiri ward, infiltration pits, deep ploughing, furrows mulching, terrace, and water pans were adopted at 77%, 68%, 61% 51%, 48% and 36%, respectively. Retention ditches, negarims, water bunds and dams were lowly adopted in Mugoiri ward at 22%, 13%, 8% and 1%, respectively. In addition, HH in Murarandia ward highly adopted infiltration pits, furrows, deep ploughing, terraces and mulching at 88%, 69%, 69%, 60% and 47%, respectively. However, there was low adoption of retention ditches, negarims, water pans and water bunds at 20%, 9%, 6% and 2%, respectively in Murarandia ward. In Wangu ward retention ditches, negarims, water pans and water bunds were lowly intensified at 27%, 12%, 9% and 6%, respectively while, infiltration pits, furrows, deep ploughing, terraces and mulching were highly adopted at 75%, 73%, 65%, 55% and 54%, respectively. Lastly, none of the HH adopted dams both in Murarandia and Wangu wards. This research study was similar to the findings of Bitok *et al*. (2023) who found that smallholder farmers adopted soil and water conservation measures including terracing, furrows, mulching and planting pits at 81.6%, 63.3%, 61.2% and 63.3% respectively.

4.5 Rainwater Harvesting for Crop Production

The study found that 86% of the HH practiced surface rainwater harvesting for different crop production enterprises while, only 10% of the sampled households practiced rooftop RWH technology for crop production (see Figure 4.7 below). In addition, only 8% of the sampled HH practiced both rooftop and surface runoff water harvesting for different crop enterprises production. In comparison, most of the HH adopted surface rainwater harvesting technologies for crop production more than those who practiced rooftop water harvesting for crop production. The findings of this study were similar to the findings by Nyaga (2021) who found that maize, bananas, coffee, avocado, tea, tomatoes, cabbage, fodder and macadamia crops were highly adopted under surface water harvesting technology as compared to rooftop technology among small-scale farmers in Kahuro, Murang’a County.

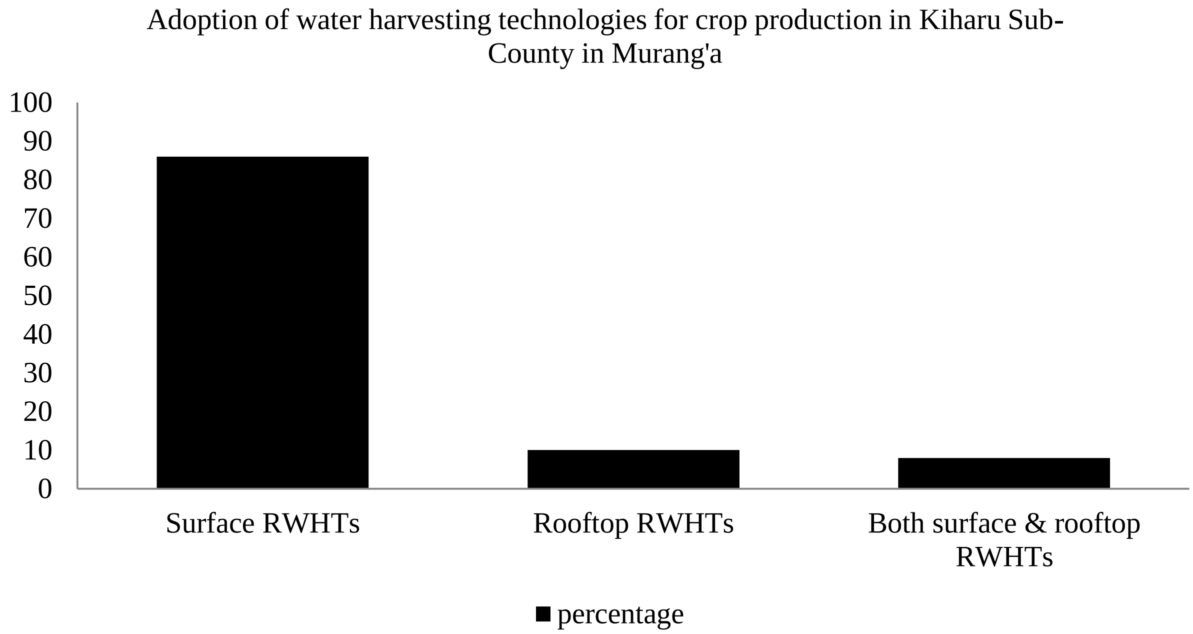

Figure 4.7: Adoption of water harvesting technologies for crop production in Kiharu Sub-County in Murang'a

4.5.1 Surface runoff water harvesting technologies for crop production

The study found that sampled HH highly adopted surface runoff harvesting for different crop production enterprises. The crop enterprises adopted under surface runoff harvesting included maize, macadamia, tea, coffee, bananas, fodder, sweet potatoes, arrowroots, beans, kales, tomatoes, spinach, cassava and French beans production. The SRWH technologies adopted were both ex-situ and in-situ surface RWHTs.. These results concur with results of (KNBS, 2019b; Maindi *et al*., 2020) and County Integrated Development Plan (CIDP, 2018). Most of the household heads in the region have highly adopted terraces, infiltration pits, mulching, furrows and deep ploughing surface runoff RWHTs. Other SRWHTs have been lowly adopted including: negarims, dams, water bunds, water pans and retention ditches (Table 4.7).

These technologies are adopted as water conservation measures in the region due to experienced rainfall variability, soil water stress and increased runoff as strategies to cope up with climate change (Bryan *et al*., 2013; Mairura *et al*., 2021; Musa *et al*., 2022; Thornton & Herrero, 2015). These results agrees with the findings of Kpadonou *et al*. (2017) and Recha *et al*. (2015) who found that farmers in West African Sahel and Tharaka sub-County Kenya, respectively highly intensified soil and water conservation technologies as RWHTs. Most of the household heads interviewed adopted more than one SRWHT.

4.5.1.1 Multivariate Probit analysis for crop enterprises under surface rainwater harvesting technologies

The different RWHTs were subjected to a multivariate test using a multivariate probit model against all the crop enterprises adopted by household heads. The independent variables were the crop enterprises while the dependent variables were the RWHTs.

Table 4.8 tabulates the multivariate tests for crop enterprises and SRWHTs adopted in the County. The regression coefficients tabulated reported the level of preference of a particular crop enterprise for a specific water harvesting technology. In addition, the present research revealed that household heads in Murang'a County utilized a combination of RWHTs for different crop enterprises. Farmers who practiced multiple crop enterprises influenced adoption of both in-situ and ex-situ technologies differently. This results concur with results of Andati *et al*. (2022); Kpadonou *et al*. (2017); Maindi *et al*. (2020); Musa *et al*. (2022) and Ondieki *et al*. (2019) done in Nyandarua County, Kenya., West African Sahel., Murang'a County, Kenya., Western Kenya and Kisii County, Kenya respectively. This is likely due to the different moisture requirements of the different crops.

Table 4.8: Multivariate probit (MVP) analysis for crop enterprises adoption under surface rainwater harvesting technologies

Variables	T Coef. (St.E)	IP Coef. (St.E)	M Coef. (St.E)	N Coef. (St.E)	Da Coef. (St.E)	WP Coef. (St.E)	WB Coef. (St.E)	F Coef. (St.E)	Re Coef. (St.E)	D Coef. (St.E)
Maize	-0.03	**1.00****	**0.41***	**-0.71****	-3.79	**0.42***	0.37	**0.51***	0.05	**0.76****
	(0.19)	(0.24)	(0.19)	(0.27)	(1089)	(0.19)	(0.49)	(0.23)	(0.23)	0.21)
Macadamia	**1.03****	**0.61***	**0.69****	**0.77****	-3.34	-0.03	0.39	-0.09	0.36	0.25
	(0.17)	(0.30)	(0.17)	(0.25)	(0.23)	(0.22)	(0.37)	(0.19)	(0.24)	(0.20)
Coffee	**1.10****	**1.05****	**0.90****	0.30	-3.06	0.36	0.26	0.03	0.06	0.28
	(0.16)	(0.27)	(0.16)	(0.26)	(1914)	(0.21)	(0.42)	(0.19)	(0.19)	(0.18)
Tea	**0.55****	**0.91****	-0.15	-0.003	-3.71	**-1.10***	-4.53	-0.24	0.03	-0.09

	(0.20)	(0.34)	(0.19)	(0.32)	(1423)	(0.43)	(195.3)	(0.22)	(0.23)	(0.23)
Avocado	0.63**	1.34**	0.34*	1.42**	-3.20	-0.04	0.25	-0.03	0.13	0.44*
	(0.16)	(0.28)	(0.15)	(0.34)	(1898)	(0.19)	(0.45)	(0.18)	(0.19)	(0.18)
Fodder	0.81**	1.07**	0.37*	0.11	-3.88	0.36	4.84	1.30**	0.20	0.25
	(0.15)	(0.23)	(0.15)	(0.27)	(1163)	(0.20)	(162.9)	(0.19)	(0.19)	(0.18)
Arrowroots	-0.24	0.52	0.61*	0.07	-3.43	0.61**	0.64**	0.74**	1.40**	0.12
	(0.18)	(0.32)	(0.25)	(0.28)	(2283)	(0.20)	(0.19)	(0.24)	(0.19)	(0.22)
Sweet	0.29	0.40	0.32	-0.13	-2.61	0.30	-0.19	0.83**	0.09	0.05
potatoes	(0.18)	(0.33)	(0.18)	(0.18)	(1087)	(0.22)	(0.35)	(0.25)	(0.34)	(0.17)
Bananas	0.93**	0.35	0.58**	0.36	-3.55	-0.11	0.20	-0.04	0.27	0.72**
	(0.18)	(0.24)	(0.16)	(0.28)	(884.8)	(0.21)	(0.45)	(0.16)	(0.20)	(0.18)
Beans	-0.13	0.64**	0.09	-0.16	-2.84	0.47*	0.42	1.21**	-0.04	0.68**
	(0.15)	(0.24)	(0.15)	(0.24)	(1502)	(0.21)	(0.33)	(0.19)	(0.17)	(0.18)
Mangos	0.80**	0.31	0.31	1.53**	-2.43	-0.28	-0.19	0.32	0.33	0.26
	(0.23)	(0.36)	(0.20)	(0.24)	(4574)	(0.29)	(0.38)	(0.25)	(0.22)	(0.26)
constant	-1.65	-2.41	-2.41	-1.83	-2.32	-1.67	-2.21	-2.94	-1.38	-2.05
	(0.26)	(0.36)	(0.33)	(0.30)	(0.33)	(0.25)	(0.37)	(0.46)	(0.23)	(0.29)

Number of observations = 384 Log likelihood = -1692.4813 Wald chi2 (110) = 731.46 Prob > chi2 = 0.0000, P < 0.01**, P<0.05*, Legends:T = terraces,IP = infiltration pits,M = mulching, N = negarim ,Da = dam(s),WP = water pans,WB = water bunds,F = furrows,Re = retention ditches,D = deep ploughing, St = standard error, Coef = coefficient

Infiltration/planting pits were the most commonly adopted technique in the region compared to other SRWHTs. 81% of the household heads interviewed in the County adopted this technique. Farmers who practiced maize, coffee, tea, avocado fodder and beans enterprises were positively significant to intensification of infiltration pits (P<0.01). Maize farmers influenced pits adoption by 1.00 coefficients while the subsequent enterprises influenced planting pits adoption by 1.05, 0.91, 1.34, 1.07, and 0.64 coefficients respectively. This exhibited that farmers who practiced avocado production highly adopted planting pits in the County. This could be a reason for increased avocado production in the County (Njuguna *et al.*, 2022) due to increased moisture availability harvested by the planting pits. In addition, farmers who practiced macadamia production positively and significantly adopted infiltration pits at ($P \leq 0.05$). The pits were highly adopted for their easy applicability in the farms during planting and extensive benefits in crop production such as: soil restoration and erosion control (Kpadonou *et al*., 2017), precise application of inputs, increased soil fertility, increased farmer's economic return and increased water infiltration and retention (Muchai *et al*., 2020). These results collaborate with results of Lutta *et al*. (2020); Mati (2006); Recha *et al*. (2015); Sidibe (2005) and Wafula *et al*. (2022). However, farmers who grew mangos, bananas, arrowroots and sweet potatoes enterprises had no statistical ($P \leq 0.05$) significance influence to planting pits adoption in the region.

Furrows were highly adopted in the region at a rate of 68%. This was the second highly adopted SRWHT in the area. Farmers who practiced fodder, arrowroots, sweet potatoes and beans production in their farms, positively and significantly adopted furrows ($p<0.01$). Fodder and beans farmers highly adopted furrows by 1.30 and 1.21, respectively. Farmers who practiced arrowroots and sweet potatoes farming significantly adopted furrows by 0.74 and 0.83, respectively. Farmers who practiced maize farming also positively and significantly adopted furrows at ($P \leq 0.05$). This indicated that farmers who practiced maize, fodder, arrowroots, sweet potatoes or beans adopted furrows. These results are comparable to Hatibu *et al*. (2003); Mak-Mensah *et al*. (2022); Pachpute *et al*. (2009); Salazar & Casanova (2011) and Wafula *et al*. (2022) results done in Tanzania., Northwest China., SSA and Katumani, Kenya. This could be due to the relatively higher moisture requirement of these crops making furrows suitable since they are able to collect more water availing it the crops for longer alleviating moisture stress. Further, the present study found that farmers who practiced macadamia, tea, coffee, avocado, mangos and bananas farming, did not adopt furrows. This could be attributed to the growth habits of these crops which having large girth, may be more suitable for harvesting water using pits or basins instead of furrows.

Murang'a County farmers also adopted deep ploughing SRWHT at a rate of 67%. This was the third highly adopted SRWH technique in the area. The results exhibited that there was a positive significant influence to the use of deep ploughing among farmers who practiced maize, beans and bananas production ($p<0.01$). Maize farmers adopted this technique by 0.76, beans by 0.68, whereas banana farmers adopted deep ploughing by

0.72. In addition, avocado farmers positively and significantly adopted deep ploughing ($P \leq 0.05$). Deep ploughing helps the farmers in breaking of hardpan layers, increasing rainwater infiltration, increased rainwater storage in the soil, increase root penetration and increased production among smallholder farming systems (Aixia *et al*., 2022). These results concur with the findings of Mzirai & Tumbo (2010); Sun *et al*. (2018) and Xue *et al*. (2019) who found out that there was increased production among smallholder farmers in Tanzania and China, respectively. This could be attributed to increased moisture availability under SRWH alleviating dry spells thus enhancing crop yield.

Household heads in the region adopted terraces at 54%. This was the fourth highly adopted SRWH technology for crop production. Both *fanya juu* and *fanya chini* terraces were adopted for diverse crop enterprises. Adoption of macadamia, coffee, mangos trees, bananas, and fodder, avocado and tea enterprises among household heads exhibited a significant influence on terrace adoption ($P \leq 0.01$). These enterprises positively and significantly influenced the adoption of terraces by the following coefficient values: 1.03, 1.10, 0.80, 0.93, 0.81, 0.63, and 0.55, respectively. This shows that farmers who practiced coffee production highly adopted terraces while, farmers who practiced tea production least adopted terraces as a surface RWHT in this region. Most farmers grew both tea and coffee in the same piece of land due to small land sizes. The increased adoption of terraces under these enterprises could be due to increased soil erosion and steep slopes present in the region thus, the technique is necessary for improved water infiltration for the production of the stated crop enterprises. The higher adoption of terraces by coffee farmers compared to tea farmers could be due to the closed canopy of tea which reduces the need for terraces compared to coffee which has a more open growth habit thus exposing the soil more to erosion. These results agree with Gikunda *et al*. (2021); Mbilinyi *et al*. (2005); Ngigi (2003a); and Waaswa *et al*. (2021) as an appropriate water harvesting technique for crop production. On the other hand, farmers growing beans, sweet potatoes, arrowroots and maize enterprises did not significantly adopt terraces. This was due to unsuitability of the enterprises’ production on terraces as they require little root penetration as compared to tea and coffee farming.

Mulching was a commonly adopted rainwater harvesting technique among the household heads in the region at 51%. This was the fourth highly adopted SRWH technique in this area. The findings from pointed out that farmers who grew maize, avocado, fodder and arrowroots enterprises had a positive significant adoption of mulching with coefficient values 0.41, 0.34, 0.37, 0.61, respectively at $P \leq 0.05$. Those who grew macadamia, coffee and bananas enterprises had a positive and significant adoption of mulching by 0.69, 0.90 and 0.59 coefficient values, respectively. These findings were in line with Binyam & Desale (2015); Nyaga (2021); Olarinde (2012); Ondieki *et al*. (2019); Rao *et al*. (2014) and Zuza *et al*. (2021). This showed that farmers who practiced coffee production are more likely to adopt mulching compared to farmers who grew macadamia, bananas, arrowroots, fodder, maize, avocado and other subsequent enterprises. Further the results suggested that mulching had a negative statistical influence to farmers who practiced tea, sweet potatoes, mangos and banana farming.

Intensity of adoption of retention ditches in the region was 23%. Only farmers who practiced arrowroots production highly adopted retention ditches. This was a positive and significant adoption ($P \leq 0.01$). The retention ditches were situated along river banks adjacent to their farms. This is a similar case to farmers who adopted water bunds as reported in this study. These structures (retention ditches and water bunds) retain a lot of water which is essential for arrow root growth. Retention ditches plays a significance role in groundwater recharge, retention of quality high amount of water and reduced water loss by controlled soil erosion (Anantha *et al*., 2021). Most of the household heads pointed out that the retention ditches adopted for arrowroots production was due to support obtained from County's extension officers. This results are similar to the findings of Nyaga, (2021). Farmers growing all other crops had a negative significant influence to adoption of retention ditches.

Water pans were also adopted among household heads in the County. The intensity of water pans adoption was 17%. Results from this research study depicted that adoption of water pans among farmers who practiced maize and beans farming had a positive significant influence. Maize farmers increased water pans adoption by 0.42 while, bean farmers increased water pan adoption by 0.47. In addition, arrowroots farmers positively and significantly ($P \leq 0.01$) adopted water pans by 0.61. This findings were comparable to Amha (2006); Binyam & Desale (2015); Boelee *et al*. (2013) and Zingiro *et al*. (2014). The results further point out that the tea farmers in the County negatively adopted water pan. This could be due to the fact that tea growing zones are inherently high rainfall zones, thus water harvesting may not be a priority. The results also exhibited that adoption of water pans among farmers who practiced macadamia, coffee, fodder, sweet potatoes, bananas and mangos enterprises was not statistically significant in the County.

The intensity of negarims adoption among household heads in the region was 12%. Findings of this study showed that household heads in this region adopted negarims for fruits trees' crop enterprises. This is because farmers who adopted avocado, mango trees and macadamia enterprises positively and significantly adopted negarims in their farms ($P \leq 0.01$). The coefficient values were (1.42, 0.34), (1.53, 0.24), **(**0.77, 0.24). Maize farmers did not adopt negarims. This could be so because negarims are more suitable for low density crops such as tree crops unlike other crop enterprises. Consequently, negarims are suitable due to their diamond-shaped structure with an infiltration pit at its lowest side (Salazar & Casanova, 2011) which traps runoff and improves water infiltration (Gladstone, 2014). It could also be due to the higher labour costs of adopting negarims which may not give a return for an annual crop like maize. The findings of the present study collaborates with the results of Mati (2006) and Recha *et al* (2015). The results further depicts that adoption of negarims among farmers who practiced coffee, tea, fodder, arrowroots, sweet potatoes, bananas and beans enterprises was not statistically significant.

Adoption rate for bunds WHT was very low (6 %) in the County compared to other SRWHTs. The results depicted that only farmers who practiced arrowroots farming significantly adopted water bunds in the County at ($P \leq 0.01$). Arrowroots farmers positively influenced water bunds adoption by 0.64. Arrowroots require high amount of water hence this could be a reason why household heads in Murang'a County adopted water bunds along riverbanks for arrowroots production hence this could be a reason for water bunds adoption among arrowroots farmers in the county. All other crop enterprises had no significance influence to water bunds adoption.

The study also indicates that only one household adopted dam RWH technology in Murang'a. Dam rainwater harvesting technique was the least adopted. Further the findings pointed out that, farmers who practiced diverse crop enterprises in the County had no significant influence to adoption of dams. The low adoption rate could be due to most of the farmers in the County are less willing to bear cost of dam construction as it is localized and costly and the technology requires large land sizes for construction (Kagombe *et al*., 2018) as well as their different farm-level, socio-economic and information sharing related factors (Timothy *et al*., 2022).

4.5.2 Rooftop water harvesting for crop production

The study found that only 10 % of the sampled HH adopted rooftop rainwater harvesting for crop enterprises in Kiharu Sub-county, Murang'a County, Kenya. Most of the household heads diverted rooftop harvested water into storage facilities such as tanks, water pans, drums, jerry cans and collection pits which was later utilized for crop production. Similar findings were reported by Ray & Chowdhury. (2016) that harvested water was diverted to storage facilities such as tanks and pits for crop and livestock production. Additionally, Pachpute *et al.* (2009) and Kattel. (2021) found that rooftop harvested water was used for crop and livestock production in South Africa and Nepal. Harvested rainwater was stored in water tanks, jerry cans, drums and water pans in the region.

The study found out that household heads in the region have adopted different crop enterprises under rooftop water harvesting technology as shown in Figure 4.8. The findings show that household heads who adopted rooftop RWHT practiced diverse crop enterprises including: maize, cabbage, fodder, arrowroots, kales, beans, tomatoes and spinach farming. These enterprises were adopted at a rate of 1%, 2%, 1%, 3%, 10%, 1%, 3%, and 8%, respectively. Crop enterprises adoption under roof top rain water harvesting technique was very low in comparison to crop enterprises adopted under surface RWHT. Further the findings exhibited that household heads in the area had not adopted some crop enterprises under rooftop RWHT such as: macadamia, coffee, tea, avocado, bananas, mangos and sweet potatoes that were adopted under surface RWHT (Figure 4.8). This may be due to the higher water required by these crops which were not adequate under the storage systems used for rooftop rainwater harvesting in Murang'a. In addition, the results depicted that tomatoes, spinach and kales crop enterprises were adopted under rooftop water harvesting technique and not under SRWHTs. This may be due to the lower water requirement of these crops or the smaller scale which enables the water stored under rooftop rainwater harvesting to be adequate for production of these crops.

This was to the contrary of the results found by Pachpute *et al*. (2009) in South Africa who found that rooftop harvested water that was diverted to tanks and water ponds was not used in crop production. However, the results were in agreement with the findings of Oweis *et al*. (2007); Recha *et al*. (2015) and Zziwa *et al*. (2018) who found that harvested rain water was used for crop production in India, Eastern Kenya and Uganda, respectively.

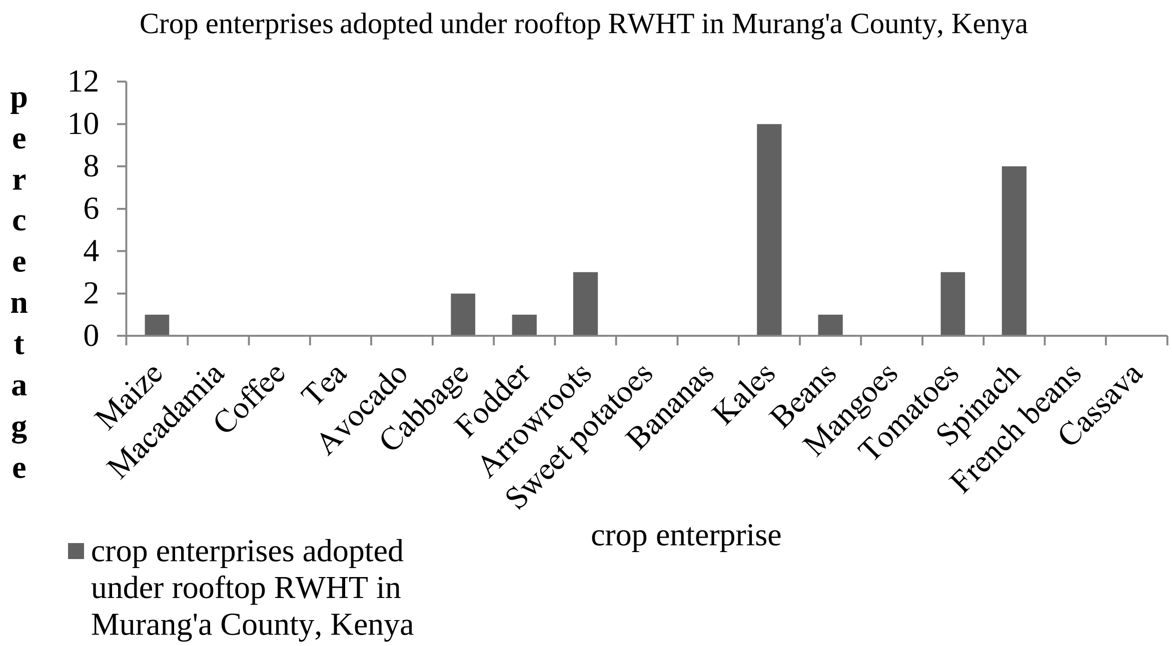

Figure 4.8: Percentage for crop enterprises adopted by HH under rooftop rainwater harvesting technology

Pearson correlation was done and the relationship between combinations of different crop enterprises adopted under rooftop rainwater harvesting as tabulated in Table 4.9.

Table 4.9: Correlation coefficients for crop enterprises practiced under rooftop RWHT among smallholder farmers in Murang'a County

Enterprises	maize	cabbage	fodder	arrowroots	kales	beans	tomatoes	spinanch
Maize	1							
Cabbage	0.441*	1						
Fodder	0.498*	-0.006	1					
Arrowroots	0.144*	0.126*	-0.008	1				
Kales	0.224*	0.347*	-0.017	0.439*	1			

Beans	0.282*	-0.010	-0.005	-0.015	0.268*	1		
Tomatoes	0.144*	0.414*	-0.008	0.384*	0.493*	-.015	1	
Spinach	0.068	0.315*	-0.015	0.572*	0.829*	0.087	0.510*	1

Asterisks* indicated correlation is significant at 0.05 levels (2-tailed).

The results found that combination of different enterprises had significant positive relationship at $P\leq0.05$ thus, interdependent. These results collaborates with the findings of Sarangi (2007), Hasimuna *et al*. (2023) and Mulokozi *et al*. (2021) who in their research findings stated that crop enterprises integration was practiced among smallholder farmers in integrated agricultural farming production systems (IAFPS) both for watershed management and increased production in India, Zambia and Tanzania, respectively. Combination of cabbage and maize production had a significant positive relation. This suggested increased combination of the two crop enterprises increased adoption of rooftop WHT. Fodder production in combination with maize farming had a significant positive relation. Fodder combined with maize enterprises positively influenced the technique adoption. On the other hand, fodder combined with cabbage enterprises had no significant relation to rooftop RWH.

Arrowroots enterprise combined with maize and cabbage production had a positive relation while arrowroots combined with fodder had a negative insignificant relation under rooftop water harvesting technique adoption. This suggested that arrowroots combined with maize and cabbage enterprises positively related by 0.144 and 0.126, respectively for rooftop RWHT. Kales enterprises had a positive relation combined with maize, cabbage and arrowroots enterprises by 0.224, 0.347 and 0.439, respectively. However a negative insignificant relation was exhibited by combination of kales and fodder enterprises**.** Beans enterprise in combination with cabbage, fodder and arrowroots respectively had a negative insignificant relationship under rooftop RWHT. However, beans production in combination with maize and kales production had a positive correlation. Beans combined with maize production positively correlated at 0.282, while beans combined with kales had a positive correlation at 0.268.

The findings also exhibited that spinach production in association with maize, fodder and beans had no significant correlation at $p<0.05$. Nonetheless, spinach combination with fodder was insignificant negatively correlated. In addition, combination between spinach and cabbage, arrowroots, kales and tomatoes enterprises were strongly and positively significant. These findings suggested that the combination of these enterprises had significant association under rooftop RWH. Spinach combination with kales was strongly correlated at 0.829, while combination between spinach and arrowroots, tomatoes and cabbage enterprises were significantly correlated by 0.572, 0.510 and 0.315 respectively. These results collaborates with the results of Das *et al.* (2014) who found that vegetable production was practiced in combination with tomatoes and other crops under rainwater harvesting technologies in India resulting to higher yields.

4.6 Rainwater harvesting for livestock production

The present study found most farmers who adopted rooftop RWH watered their livestock using rooftop harvested water while, a small percentage practiced aquaculture. Most of the household heads highly practiced dairy cattle farming (12%) as compared to other livestock enterprises in this study. The findings further exhibited that household heads who practiced goat rearing, sheep farming, beef cow rearing, pig production, and poultry farming watered their livestock using rooftop harvested rainwater at a rate of 10%, 9%, 6%, 3% and 6%, respectively as shown in Figure 4.9.

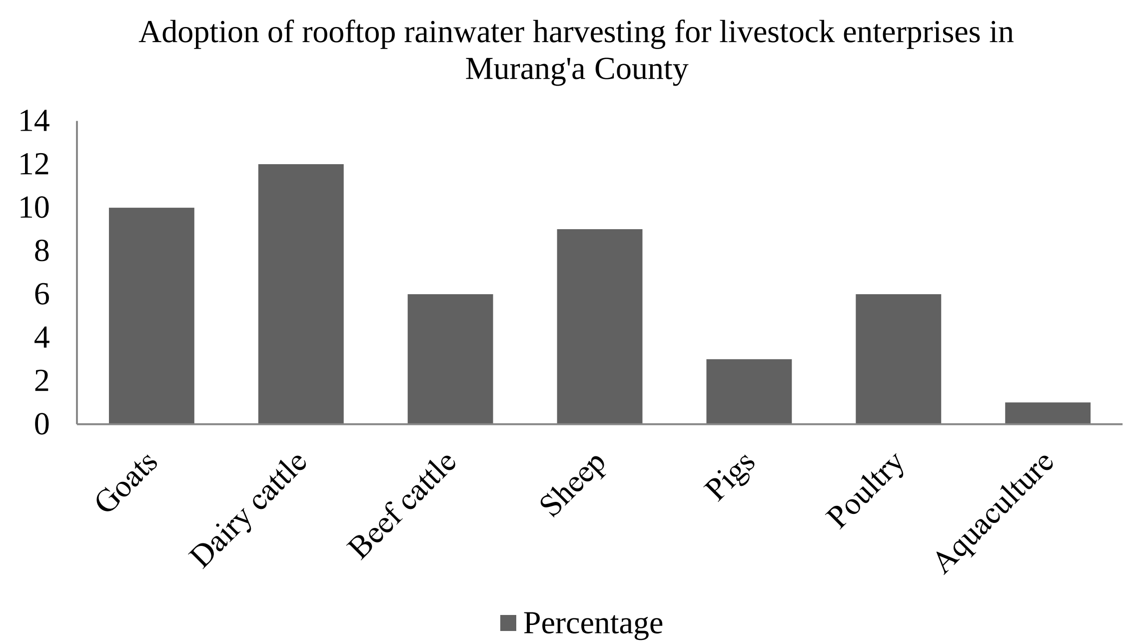

Figure 4.9: Adoption of rooftop rainwater harvesting technology for livestock enterprises in Murang’a County

Rooftop rain water was harvested during the rainy season and stored for use during the dry seasons. Rooftop harvested water was stored in various water storage facilities including: tanks, water pans, jerry cans, drums and bottles for livestock production. The results of this study were comparable to the results found by Giffoni *et al*. (2019); Kimani *et al*. (2015); Kimutai & Bwisa. (2015); Nyaga. (2021) who found that harvested rain water was stored in distinct storage facilities in Brazil, Makueni County, Kenya, Thika East Sub-County, Kenya and Murang'a County, respectively. However, this was a low adoption as compared to other studies done in other parts of Central Kenya. Reasons for low rooftop RWH adoption rate may be due to high maintenance costs of rooftop catchment system, storage limits, high initial costs, chemical seepage from some roof types and unpredictable rainfall patterns (Wanyonyi, 2013; Worm, 2006).

Table 4.10 represents the correlation between different combinations of livestock enterprises adopted under rooftop RWHT among household heads in Murang'a County.

Table 4.10: Correlation Coefficients for livestock enterprises adoption under rooftop RWH among household heads in Murang'a County (N=384)

Enterprises	Goats	Dairy cows	Beef cows	Sheep	Pigs	Poultry	Aquaculture
Goats	1	0.648**	0.527**	0.552**	0.341**	0.631**	0.193**
Dairy cows		1	0.560**	0.670**	0.481**	0.523**	0.097
Beef cows			1	0.471**	0.325**	0.446**	0.255
Sheep				1	0.250**	0.382**	0.121*
Pigs					1	0.342**	-0.021
Poultry						1	0.169**
Aquaculture							1

Note asterisks**, and * shows correlation is significant at 0.01 level and 0.05 levels respectively

The findings indicate that most of the livestock enterprises were positively correlated thus, interdependent. This suggested that the farmers in the region would make a judicious decision on combination of livestock enterprises watering using rooftop harvested rainwater. The association between goat husbandry and the other six subsequent livestock enterprises (dairy cattle, beef, sheep, pigs, poultry and aquaculture) had a positive significant correlation under rooftop RWH technique adoption ($p<0.01$). This agrees with Hasimuna *et al*. (2023) who found that cattle production, poultry, piggery, sheep and aquaculture are integrated in most African countries. This depicts that farmers who practiced goat husbandry used rooftop harvested rainwater to water their goats as well as other subsequent enterprises. Farmers who practiced goat rearing in this region had a positive correlation to rooftop RWHT in association with dairy farming, beef cows farming, sheep husbandry and aquaculture (Table 4.10). These results are in agreement with the findings of Alamerew *et al*. (2002); Castelli *et al*. (2017) and Vetter *et al*. (2009) who found that goats production was practiced in combination with: sheep in Ethiopia, sheep and Goats in Ethiopia and poultry and goats in Egypt.

Dairy cattle farmers in combination with beef cattle, sheep, pig and poultry farmers significantly and positively adopted rooftop RWHT ($p<0.01$). The findings further pointed out that combination of aquaculture and dairy farming in Murang'a was positively insignificant when practiced under rooftop RWHT (Table 4.10). These results agree with the findings of Das *et al*. (2014) who found that farmers in India reared dairy cattle in combination with pigs and fisheries under rainwater water harvesting for increased economic gains but also contradicts results of Mulokozi *et al.* (2021) and Hasimuna *et al*. (2023) who found that integration of livestock and fish farming was practiced in Tanzania and Zambia, respectively. These differences could be due to the water storage capacities of the roof rainwater harvesting technologies in different studies and the different cattle production systems adopted at different geographical regions.

Farmers in Murang'a County also practiced beef cattle husbandry in combination with other livestock enterprises. Beef cattle farming in combination with sheep, pigs and poultry production had a positive correlation and influence to rooftop water harvesting adoption for livestock watering in the area. Beef cattle farming combined with stated livestock enterprises had a positive influence at $p<0.01$. These results are in agreement with Das *et al*. (2014) findings who stated that cattle production was integrated with other livestock enterprises in India. However, in the present study, there was no relationship between beef cattle and aquaculture production. This contradicts the results of Das *et al.* (2014) who found that cattle production and aquaculture were jointly adopted in India and Hasimuna *et al*. (2023) whose findings indicate that aquaculture was highly integrated with other livestock enterprises in Zambia. These differences could be attributed to the stages of aquaculture development in the different study locations.

Sheep production in combination with fish farming had a positive correlation under rooftop RWHT adoption ($p<0.05$). This indicated that HH who practiced a combination of the two enterprises (sheep and aquaculture production) increased rooftop RWHT adoption. This contradicts results found by Castelli. (2017) that mixed sheep-goats production systems was practiced in Southern Tigray, Ethiopia. The results further deduced that combination of sheep production with pigs and poultry farming also had a positive relation to increased adoption of rooftop RWH technique. These collaborates with results of Alamerew *et al*. (2002) who stated that sheep production was practiced in combination with poultry under rainwater harvesting in Werodo, Northern Ethiopia. The positive correlations indicated that combination of sheep rearing with pig production and poultry production had a positive relationship to adoption of rooftop RWHT.

Correlation between pig production and aquaculture was negative. This suggested that smallholder farmers in Murang'a County were unlikely to practice fish and pig farming in combination. This could be attributed to the confines pig production systems in the county. Pig production had a positive and significant correlation with poultry farming. This shows that farmers who practiced pig farming combined with poultry farming had positive relationship with adoption of this technique by 0.342 ($p<0.01$). There was no significant relationship between farmers who reared poultry and pigs on rooftop RWH technique adoption. This suggested that farmers who practiced poultry farming in combination with pigs had no significant influence to rooftop RWHT. This results contradicts Mulokozi *et al*. (2021), Sarangi (2007) and Hasimuna *et al*. (2023) who found that livestock enterprises were integrated together in Tanzania, India and Zambia respectively for increased productivity and income. The study also found that poultry farming had a positive relationship in combination with fish farming. These results agree with the findings of Sturm *et al*. (2009) who found that poultry farming was integrated with fish farming in Namibia. Combination of these two practices positively influenced the use of rooftop harvested water in Murang'a.

4.6.1 Factors influencing adoption of RWHTs in Murang'a County

The table below show multivariate probit model estimates for the factors that influenced rainwater harvesting technologies in the study area. The results exhibited both positive and negative influence of RWHTs.

Table 4.11: Determinants for adoption of Rainwater harvesting technologies among smallholder farmers in Murang’a County, Keya

Variables	RTH	T	IP	M	N	W	F	RD	DP
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
	Std. E	Std. E	Std. E	Std. E	Std. E	Std. E	Std. E	Std. E	Std. E
Socio-demographic factors									
Gender	0.19	**-0.59*** **	-0.04	-0.04	-0.13	**-0.57***	-0.01	**0.37***	-0.29
	(0.29)	**(0.17)**	(0.20)	(0.17)	(0.24)	**(0.23)**	(0.17)	**(0.18)**	(0.17)
Age	0.25	0.20*	0.16	0.05	0.01	-0.02	0.24*	0.17	0.19
	(0.16)	(0.10)	(0.12)	(0.10)	(0.14)	(0.12)	(0.10)	(0.11)	(0.10)
Education	**0.32***	-0.11	**-0.45****	-0.17	-0.25	-0.05	**-0.24***	**-0.26***	-0.21
	(0.18)	(0.11)	**(0.14)**	(0.11)	(0.14)	(0.12)	**(0.11)**	**(0.11)**	(0.11)
Household size	0.11	-0.06	0.14	**0.19***	0.19	0.18	0.13	0.04	-0.01
	(0.15)	(0.10)	(0.11)	**(0.10)**	(0.14)	(0.12)	(0.10)	(0.11)	(0.10)
Distance to	-0.01	**0.19***	0.11	0.05	0.05	**0.15***	0.10	0.10	-0.04
source of water	(0.13)	**(0.08)**	(0.10)	(0.08)	(0.11)	**(0.09)**	(0.09)	(0.09)	(0.10)
Socio-economic factors									
Land ownership	0.61	-0.16	**0.54***	**0.53***	-0.05	-0.12	**0.69****	0.55	**0.54***
	(0.32)	(0.24)	**(0.24)**	**(0.24)**	(0.32)	(0.28)	**(0.23)**	(0.30)	**(0.23)**
Group	-0.10	**0.39***	0.33	0.16	0.23	0.27	**0.36***	**0.36***	**0.49****
membership	(0.30)	**(0.17)**	(0.21)	(0.17)	(0.21)	(0.19)	**(0.18)**	**(0.18)**	**(0.18)**
RWH Training	**0.72***	0.26	-0.04	0.26	**0.41***	0.10	0.11	**0.35***	0.01
	(0.29)	(0.15)	(0.17)	(0.15)	**(0.20)**	(0.18)	(0.15)	**(0.16)**	(0.15)
Source of income									
Business person	0.26	0.16	0.15	0.10	0.36	-0.23	0.18	0.33	**0.36***
	(0.28)	(0.17)	(0.20)	(0.17)	(0.22)	(0.20)	(0.18)	(0.18)	**(0.18)**
Farming	-0.26	**0.35***	0.25	**0.32***	-0.05	-0.03	0.10	0.08	0.23
	(0.25)	**(0.16)**	(0.18)	**(0.15)**	(0.20)	(0.18)	(0.16)	(0.16)	(0.16)
Pension	**-1.10***	0.63	0.84	0.01	0.43	**-0.85***	-0.35	-0.34	0.01
	(0.47)	(0.35)	(0.56)	(0.33)	(0.37)	**(0.41)**	(0.33)	(0.35)	(0.33)
Casual labor	-0.08	-0.01	0.31	0.14	0.17	**-0.41***	0.30	0.03	0.27

	(0.27)	(0.17)	(0.20)	(0.17)	(0.22)	**(0.20)**	(0.17)	(0.18)	(0.17)
Institutional factors on credit access									
Sacco	-0.45	-0.13	0.37	**0.46****	0.23	**0.66*****	0.02	0.28	0.26
	(0.26)	(0.17)	(0.21)	**(0.17)**	(0.21)	**(0.19)**	(0.17)	(0.18)	(0.17)
Micro-finance	0.10	-0.21	0.16	0.29	-0.12	0.49	0.17	**-0.57***	0.10
	(0.40)	(0.23)	(0.30)	(0.23)	(0.31)	(0.27)	(0.24)	**(0.25)**	(0.24)
Farmer's groups	0.18	**-0.48****	0.05	0.23	0.02	0.20	-0.04	0.10	-0.17
	(0.27)	**(0.18)**	(0.21)	(0.20)	(0.24)	(0.21)	(0.18)	(0.20)	(0.18)

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Multivariate probit (SML, # draws = 5), Number of observation = 384, Wald chi2(135) = 262.04, Log likelihood = -1495.326, Prob > chi2 = 0.0000, chi2(36) = 274.946 Prob > chi2 = 0.0000, Legends RTH= rooftop rainwater harvesting technique, T= terraces, IP= infiltration pits, M=mulching, N=negarims, W=water pans, F=furrows, RD=retention ditches and DP=deep ploughing

4.6.1.1 Socio-demographic determinants

Gender of the HH negatively influenced the adoption of terraces and water pans at P<0.001 and p<0.05 respectively in Murang'a County. The study found that male-headed households were more as compared to female-headed households. This means that there were more male-headed households in Murang'a as compared to female-headed households. The negative sign suggested that gender of the HH would decrease the adoption of terraces and water pans RWHTs in the region thus female-headed households were more likely to adopt terraces and water pans in comparison to male-headed households.This resulted due to differences and gender gap in decision making process between women and men-headed households on the type of RWHT as a climate smart agricultural practice (Mairura *et al*., 2021; Okello *et al*., 2018; Theis *et al*., 2018; Waaswa *et al*., 2021) in the area. This study found that male-headed households are more likely to adopt RWHTs as compared to female headed households in the area. These results are contrary with the studies done by Musa *et al* (2022) who pointed out that female smallholder farmers had a higher likelihood to intensify sustainable agricultural practices such as RWHTs than male-headed households in Western Kenya. This difference in adoption between Central and Western Kenya could be attributed to cultural differences in the two regions. However, gender was positively significant to increased adoption of retention ditches technique ($p<0.01$). This pointed out that male headed households were more likely to adopt retention ditches in Murang'a than female-headed households. These results were similar to the results of Kpadonou *et al.* (2017) who suggested that male led households are more likely to adopt soil and water conservations measures as one of the climate smart agricultural practices intensified in West African Sahel as compared to female led households.

Household head's age had a positive significant influence to adoption of terraces and furrows ($p<0.05$). This exhibited that increase in age of the HH increased adoption of terrace and furrows technologies by 0.203 and 0.241, respectively. This is because older people in Murang'a County are more experienced and highly skilled in both traditional and emerging agricultural technologies than young people and thus are more likely to adopt the two water harvesting technologies (terraces and furrows) as compared to young farmers in the region. In addition, young farmers in Murang'a County were less informed on the benefits of intensifying water harvesting in comparison to older farmers hence, the low adoption. These results concur with the findings of Jan. (2020) who found that older people adopted new water harvesting technologies in Arid and semi-arid areas of Pakistan more than young farmers because older famers were more informed on the benefits resulting from adoption of new WHT in the region. The current study further demonstrated that older people adopted RWHTs as compared to youthful generation. This was contrary to the findings of Baiyegunhi. (2015) and Belachew *et al*. (2020) who observed that farmer's age increase by one year decreased the likelihood of rainwater harvesting adoption in South Africa and Ethiopia respectively. This was attributed to the fact that young smallholder farmers adopted new agricultural technologies in the respective countries as compared to older smallholder farmers.

Household size was also a key determinant for rainwater harvesting technologies in Murang'a. Household size exhibited a positive significant relationship to increased adoption of mulching surface water harvesting technique ($p<0.05$). This suggested that increase of farmers by one member in a household positively influenced an increase in adoption of mulching as a water harvesting technique. Increased adoption of these technologies was due to increased human capital from the increased household size thus adequate labor for adoption of mulching and deep ploughing technologies (Belachew *et* *al.*, 2020). The findings of the present study were comparable to the results of Kpadonou *et al*. (2017) and Musa *et al*. (2022) who found that household size positively influenced intensification of soil and water conservation measures as water harvesting technologies in Ethiopian highlands and Western Kenya, respectively. However, the results of the present study disagreed with Andati *et al*. (2022) and Bryan *et al*. (2013) who found that increase in family size had a negative relationship to water harvesting adoption by potato farmers in Kenya and adoption of good agricultural practices (GAPs) for climate adaptation in Kenya, respectively due to availability of other alternative water sources such as springs and rivers in their region.

Distance to source of water exhibited a positive significant influence to terraces and water pans rainwater harvesting technologies adoption. Source of water significantly and positively influenced the adoption of terraces and water pans. The results of this study agree with the findings of Mango *et al*. (2018) and Ngango & Hong. (2021) who found that that smallholder farmers who relied on surface water as the main source of water for small scale irrigation practices positively influenced adoption of rainwater harvesting technologies such as terraces and water ponds in South Africa and Rwanda, respectively. Significant influence to water pans adoption in the present study was attributed to larger distance away from water sources hence farmers adopt the technique to store harvested rainwater in water pans and use it for irrigation (Mango *et al*., 2018) under different agricultural enterprises.

4.6.1.2 Socio-economic determinants

Household head membership to a farmer's group had a positive significant influence to adoption and utilization of RWHTs in Murang'a County. The findings of the present study found membership of a HH to a farmers group increased the propensity of a HH to adopt terraces, furrows, retention ditches and deep ploughing technologies. This suggested that household heads who were members to a farmers' group significantly influenced an increase in adoption of deep ploughing. Further, the results showed that membership to farmers' group(s) positively increased the adoption of terraces, furrows and retention ditches ($p<0.05$). Farmers' group membership exhibited several benefits to HH which positively influenced adoption of RWH technology. These benefits include: training, credit access, social ties and information access for RWH as shown in

Table 4.12. The findings of this research study collaborated with the results found by Mango *et al*. (2018), Muchai *et al*. (2020), Ngango & Hong. (2021), Reza *et al*. (2018) and Wamunyu *et al*. (2017) in South Africa, Eastern Kenya, Rwanda, Indonesia and Murang'a County, Kenya respectively. The authors found that household heads and smallholder farmers who were members of farmers groups gained the stated benefits in the present study increasing the adoption rate of water harvesting technologies.

Table 4.12 showed that the four benefits had a positive significant association in combination. This showed that HH interdependently used the benefits gained from their farmers' group to adopt a rainwater harvesting technique in Murang'a County. These results showed that membership to farmers' group increased social ties among smallholder farmers hence increased access to information, training and credit facilities for adoption of RWHTs. In addition the findings also revealed that increased access to credit increased the likelihood of trained smallholder farmers in the region for increased adoption of RWHTs. Lastly the results revealed that trained smallholder farmers in farmer's groups were more likely to borrow credit, increases social ties and facilitated access to information hence increasing the adoption of RWHTs. This is one of the reasons for increased adoption of terraces, furrows, retention ditches and deep ploughing water harvesting technologies in the study area. Further local members from local institutions such as groups are able to pool resources together hence easing access to necessary resources for adoption of an agricultural technology (Murgor *et al*., 2013; Teklewold *et al*., 2017; Waaswa *et al*., 2021). These results were similar to the findings of Bitok *et al.* (2023) and Kifle *et al.* (2022) who found that membership to farmer's groups among smallholders increased utilization of CSA technologies in Kenya and Ethiopia respectively.

Table 4.12: Correlation matrix of the benefits for household heads' group membership

Variables	Trainings	Credit access	Social ties	Information access
Trainings	1.000			
Credit access	0.260**	1.000		
Social ties	0.205**	0.294**	1.000	
Information access	0.336**	0.330**	0.697**	1.000
Spearman rho = 0.697				

Asterisks** indicated statistical significance at ($P<0.05$)

Land ownership exhibited an increased propensity to adoption of infiltration pits, mulching and deep ploughing RWHTs at 5 % level of significance. Household heads who owned land positively influenced adoption of infiltration pits, mulching and deep ploughing WHTs. In addition, ownership of land also had a positive significant influence to increased adoption of furrows water harvesting technique. These findings implied that household heads who owned land either by owning a title deed or by leasehold terms had a higher likelihood of intensifying multiple water harvesting technologies which included mulching, planting pits, deep ploughing and furrows in Murang'a County. This was attributed to more security of land tenure as compared to HH who owned their land on lease terms. The findings of the present study collaborates with Kpadonou *et al*. (2017) and Mangisoni (2019) who pointed out that smallholder farmers who owned their land with title deeds adopted more water conservation technologies on their farms due to positive perception on their land security in West African Sahel and Southern Malawi, respectively.

Studies have demonstrated that adoption of water harvesting technologies and sustainable land management practices are positively related to education status (Tesfaye, 2017). Education unexpectedly decreased the rate of adoption of some of the rainwater harvesting technologies in the current study. Education of the household head negatively influenced adoption of infiltration pits ($p<0.01$), furrows ($p<0.05$) and retention ditches ($p<0.05$). Higher education level of the HH decreased the adoption rate of infiltration pits and retention ditches. This was contrary to the results of Kpadonou *et al*. (2017), Lutta *et al*. (2020) and Musa *et al*. (2022) done in West African Sahel, South Eastern Kenya and Western Kenya, respectively who pointed out that educated farmers were more likely to adopt planting pits and retention ditches water harvesting technologies than non-educated smallholder farmers. This decreased adoption of infiltration pits and retention ditches in Murang'a County. This could be due to other suitable alternative water harvesting technologies that were more preferred among households. However, education had a positive significant influence to increased adoption of rooftop rainwater harvesting ($p<0.05$). This suggested that highly educated farmers were more knowledgeable thus had more skills for rooftop harvesting systems installation in their households contrary to the uneducated households. These findings concur with the results of Adhikari *et al*. (2018); Akroush *et al*. (2016) and Kimani *et al*. (2015) done in Makwanpur district of Nepal, Jordan and Makueni County, Kenya respectively who found that educated smallholder farmers are more likely to adopt rooftop and other water harvesting technologies than non-educated farmers.

Different sources of income exhibited both negative and positive influence to adoption of different RWHTs in Murang'a. Household heads who relied on farming and business persons as their main sources of income positively influenced the adoption of deep ploughing, terraces and mulching water harvesting technologies ($p<0.05$). Household heads who relied their source of income as businesspersons had propensity to increase the adoption of deep ploughing while, HH who relied on farming as their main source of income had a likelihood of adopting terraces and mulching water harvesting technologies. In addition, HH who relied on farming and business stated that they adopted mulching and deep ploughing because they were more cost effective to establish and maintain as compared to dams, water pans, retention ditches and negarims. This mean that little capital was required for a HH to adopt these water harvesting technologies. This findings agreed with the results of Baiyegunhi (2015) and Okello *et al*. (2021) who found that income availability significantly increased water harvesting and other agricultural technologies' adoption in South Africa and Kenya respectively. However, HH who relied on pension and casual labor sources of income negatively influenced RWHTs adoption. Household heads who relied on casual labor negatively influenced the adoption of water pans. In addition, HH who relied on pension negatively influenced adoption of rooftop water harvesting and water pans by -1.099 and -0.852 respectively. This means that income obtained by HH was inadequate hence impeded the ability to invest in water pans harvesting technology in Murang'a County. These results contradicts Alam (2015) and Timothy *et al*. (2022) findings who reported that availability of sources of income such as pension resulted to an increasing intensification of agricultural technologies such as small scale RWH in Indonesia and Tanzania respectively. This pointed out that smallholder farmers in Indonesia and Tanzania invested their pension on RWHTs as a water management technology for domestic reasons and agricultural production which is similar to the present study.

Training on rainwater harvesting technologies showed a positive significant influence to adoption of water harvesting technologies in Murang'a County. Training increased the propensity of intensifying rooftop water harvesting, negarim and retention ditches in the region. Most of the trained HH reported that they obtained training services from the Sub- County agricultural extension officers and non-governmental organizations hence increased adoption of water harvesting technologies. Household heads who had accessed training services significantly influenced the adoption of rooftop water harvesting. This implied that access to training services and information increased the adoption of rooftop rain water harvesting. These findings collaborated with the results of Kimani *et al.* (2015) who pointed out that trained farmers in Makueni County had more access to information from trained farmers who influenced other non-trained farmers to adoption of water harvesting technologies. Consequently, access to training exhibited a positive significant influence to adoption of negarims and retention ditches. Similar observation were made by Belachew *et al*. (2020), Kimani *et al*. (2015) and Mairura *et al*. (2021) who found that access to training increased RWH intensification in Southwest Ethiopian highlands, Makueni County in ASALs of Kenya and Central highlands of Kenya, respectively.

4.6.1.3 Institutional determinants

The principal institution determinants in this study were sources of credit among HH in Kiharu Sub County. Access to credit exhibited both positive and negative significant influence to water harvesting adoption. The present study found a positive relationship between credit availability by the HH to their level of water harvesting technology adoption. Access to credit increased the level of adoption for mulching and water pans technologies. Mekuria *et al*. (2020); Gichangi & Gatheru (2018); Ngango & Hong (2021) and Wamunyu *et al*. (2017) found similar results that access to credit facilities provided ready capital thus increased level of adoption of agricultural technologies including water harvesting technologies in Ethiopia, Eastern Kenya, Rwanda and Murang'a County, Kenya respectively. However, HH who accessed credit from micro-finance and farmers' groups negatively influenced the adoption of retention ditches and terraces adoption. The main reason for this was that credit obtained from farmers' groups and microfinance was inadequate and thus used for alternative and cost-effective agricultural technologies. These findings collaborates with the study done by Akroush *et al.* (2016)who found that credit services did not significantly influence the propensity of adopting a RWHT in arid areas of Jordan region.

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS AND FURTHER RESEARCH

5.1 Chapter overview

This chapter mainly focused on the conclusions based on the three research objectives. Secondly, recommendations were also made based the conclusions of the main research findings and lastly suggestions on the future research were clearly outlined based on the research gaps identified and drawn from the present research study in Kiharu Sub County, Murang'a County.

5.2 Conclusion

This study sought to determine the adoption of rainwater harvesting technologies utilized by smallholder farmers in Murang'a County. It found that the intensity and adoption of rainwater water harvesting in Murang'a County varied depending on the enterprises practiced among household heads. The conclusions drawn from the findings were: the main water harvesting technologies adopted were rooftop and surface runoff RWHTs that included both ex-situ and in-situ RWHTs such as: terraces, retention ditches, mulching, water pans, water bunds, negarims, furrows, deep ploughing, infiltration pits. Further, the research study concluded that infiltration pits, furrows and deep ploughing were the most intensified surface water harvesting technologies while dams, water bunds, retention ditches and negarims were least intensified in the area. In comparison, rooftop technology was highly adopted than surface runoff water harvesting technologies.

Secondly, this study evaluated the crop and livestock enterprises adopted under rainwater harvesting among smallholder farmers in Muranga County. On this, the study found that: the different water harvesting technologies were adopted for different crop and livestock enterprises with rooftop technology lowly adopted for both crop and livestock enterprises while, surface RWHT was highly adopted for crop enterprises. However, no surface RWHT was adopted for livestock production. The key crop enterprises adopted by smallholder farmers under the surface rainwater harvesting technologies in Murang'a county were: macadamia, maize, coffee, tea, avocado, fodder, arrowroots, beans, bananas, mangoes and sweet potatoes In spite of high adoption of crop enterprises under Surface RWHTs, some crop enterprises under surface RWHTs were not practiced under rooftop RWHT including: spinach, tomatoes, beans, arrowroots, kales, fodder, cabbage and maize crop enterprises.

Finally, the study determined the socio-economic, institutional and socio-demographic factors influencing adoption of rainwater harvesting technologies among smallholder farmers in Murang'a County. The study found several determinants for adoption of rainwater harvesting technologies. These included: sources and access to credit, farmer's training on different RWHTs, membership to farmers' groups, education level, gender, sources and levels of income, land ownership, age, information access and distance to sources of water.

5.3 Recommendation

The study gives the following recommendations:

On the first objective, the county government, policy makers in collaboration to other relevant stakeholders should initiate interventions and create awareness among smallholder farmers in Murang'a County on the benefits of adoption of both surface and rooftop water harvesting technologies in the region during dry spells periods. Creation of awareness on the lowly intensified surface rainwater harvesting technologies including: negarims, water bunds, water pans and retention ditches.

Secondly the relevant stakeholders should provide policy recommendations on non-adoption of surface RWHTs on livestock watering as well as on the low adoption of crop & livestock enterprises under rooftop water harvesting technology among smallholder farmers in Murang'a County.

Further, the results suggest that policy interventions be done targeting the determinants (institutional, socio-economic and socio-demographic factors) which have the potential to increase adoption of RWHTs among smallholder farmers in Murang'a County. The relevant stakeholders including the County government and NGO's implementing the technologies should encourage smallholder farmers including the youths to join social groups for increased social networking and interconnectedness which will positively promote the adoption rate due to increased awareness and exposure to more training for the different water harvesting technologies. However, the financial institutions should create awareness on the benefits of credit borrowing for adoption of RWHTs among smallholder farmers in the region.

5.4 Further research

Our findings suggested future research on low adoption of dams, water bunds, retention ditches and water pans water harvesting technologies in Murang'a County. Other suggestions were on: preference for surface RWHT or rooftop RWHT for some crop enterprises, reasons for non-adoption of macadamia, tea, coffee, avocado, mangos and bananas farming under furrow technology, low adoption of rooftop harvested water for both livestock watering and crop production, non-adoption of harvested surface runoff water for livestock watering and lastly on the negative influence of gender, income sources and credit access to adoption of rainwater harvesting technologies.

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APPENDICES

Appendix 1: Questionnaire

This questionnaire has been purposely prepared to help the research in data collection on social factors determining rainwater harvesting adoption and the agricultural enterprises adopted under RWH among smallholder farmers in Murang'a County. Please note that any information given herein was to ensure confidentiality and only used for the purpose of this exercise.

Section 1.Bio-data details

Name of the enumerator

Name of the respondent

County…………… Sub-county…………………. Location………………….

Village……………………………………………......

Date of the exercise………………………………………..

Section 2. Background information

2.1 GPS coordinates of the household

2.2 Gender of the household head (HH) 1=Male [ ] 2=female [ ]

2.3 Age of the household head (years) 1=18-35 [ ] 2=36-45[ ] 3=46-60[ ] Over 60[ ]

2.4 Education level of the household head 1=Tertiary level [ ] 2=Secondary level [ ] 3=Primary school 4=none [ ]

2.4.1 If none, is there a learned household member who helps in rainwater harvesting technology adoption? 1=Yes [ ] 0=No [ ]

2.5 Household size 1=1-5 [ ] 2=6-10 [ ] 3=> 10 [ ]

2.6 What are your main sources of income?

1=Salary (employed) [ ] 2=Businessperson [ ] 3=Farming [ ] 4=Pension [ ] 5=Casual labor [ ] 6=Remittances [ ] 7=other [Specify ….]

2.6.1 What is the level of each of your main sources of income selected above?

1=Below Ksh.10, 000 [ ] 2=Ksh.10, 000 to 50, 000 [ ] 3=Ksh.50, 000 to 100, 000 [ ] 4=Above Ksh. 100, 000 [ ] 5= Not a source

2.7 What is the ownership status of your farm? 1= Leased land 2= own title deed 3=others (specify)

Section 3. Water availability and utilization of RWH

3.1 What is the main source of water in your household? (1) River (2) piped (3) borehole (4) Dam (5) Rain (6) well

3.2 Rather than the above source do you practice rainwater harvesting in your homestead? 1=Yes [ ] 0=No [ ]

3.2.1 If yes, (from 3.2) for what reasons do you harvest rainwater? 1=Domestic purposes [ ] 2=Livestock production [ ] 3=Crop production [ ] 4= all of the above

3.2.2 If No, why do you not practice rainwater harvesting? (1) Expensive (2) not interested (3) laborious (4) land constraints (5) Inadequate information access

3.2.3 If yes, (*from3.2*) how long have you been harvesting rainwater? 1=1-5 years [ ] 2=6-10 [ ] 3=above 10 years [ ]

3.2.3.1 If yes, what methods have you adopted (1) In-situ catchments (2) Ex-situ catchments (3) Both

3.2.3.2 Photo of the rainwater harvesting technique(s)

3.2.4 If yes *(from section 3.2.2.1)*, have you been practicing any of the following techniques in your household? 1=Rooftop water harvesting 1=Yes [ ] 0=No [ ] 2=Surface rainwater harvesting 1=Yes [ ] 0=No [ ]

3.6.1 If you practice rooftop water harvesting, do you store harvested water? 1=Yes 2=N/A 0=No [ ]

3.6.2 If yes, where do you store your harvested rainwater? 1=Water tanks [ ] 2=water pans [ ] 3=jerry cans 4=bottles [ ] 5= any other

Section 4. Livestock enterprises under RWH

4.1 What rainwater harvesting techniques have you adopted for livestock watering? (*Tick appropriately) 1*=Rooftop harvested water [ ] 2=Surface runoff [ ] [ ] 3= None of the above [ ] 4=both

4.2 If rooftop harvested water, what type of livestock do you water using harvested rainwater in 2021? *(Tick and indicate where appropriate)*

Livestock type	**Number**
Goats	
Dairy cows	
Beef cows	
Sheep	

Pigs	
Poultry	
Aquaculture	

4.3 If No, for what reasons don't you water your animals using rooftop water harvesting? (1) Roof tops may seep chemicals (2) requires high initial cost requires (3) high maintenance cost (4) other sources of water (5) Unpredictable rainfall

4.4 If surface runoff harvested water, what livestock enterprises do you water using runoff harvested water?

Livestock type	**Number**
Goats	
Dairy cows	
Beef cows	
Sheep	
Pigs	
Poultry	
Aquaculture	

Section 5. Crop enterprises under rainwater harvesting

5.1 Do you practice crop production under rainwater harvesting in your farm? 1=Yes [ ] 2=No [ ]

5.2 What rainwater harvesting techniques have you adopted for crop production? 1=Surface runoff harvesting [ ] 2=rooftop water harvesting [ ] 3=both [ ]

5.3 Photo of the site………………………………

5.4 If yes, what crops do you grow under each of the above stated harvesting techniques? 1=Food crops 2=Cash crops 3=Both 4= none of the above

5.5 What crop enterprise have you adopted under surface runoff harvesting?

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbages [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

5.6 What crop enterprise have you adopted under rooftop water harvesting?

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbages [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

5.7 Have you been practicing any of the below rainwater harvesting techniques in your farm? *(Tick where appropriate)* 1=Terraces [ ] 2=Infiltration pits [ ] 3=Mulching [ ] 4=Negarims [ ] 5=Water pans [ ] 6=Water bunds [ ] 7=Furrows [ ] 8= Retention ditches [ ] 9=Deep ploughing [ ]

5.8 What crop enterprises have you adopted under each rainwater harvesting technique practiced in your farm?

a) Terraces

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbages [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

b) Infiltration pits

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

c) Mulching

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

d) Negarims

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

e) Water bunds

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

f) Water pans

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

g) Water bunds

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

h) Furrows

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

i) Retention ditches

1=Maize [ ] 2=Macadamia [ ] 3=Coffee [ ] 4=Tea [ ] 5=Avocado [ ] 6=Cabbage [ ] 7=Fodder [ ] 8=Arrowroots [ ] 9=Sweet potatoes [ ] 10=Bananas [ ] 11=Kales [ ] 12=Beans [ ] 13=Mangoes [ ] 14=tomatoes [ ] 15=spinach [ ] 16=French beans [ ] 17=Cassava [ ]

<u>Section 6: Extension services and information access</u>

6.1 Have you accessed any information from an extension agent on rainwater harvesting this year (2021)? 1=Yes [ ] 0=No [ ]

6.1.1 If yes, how frequent? 1=Once a week [ ] 2=every fortnight [ ] 3=Once a month [ ] 4=Twice a year [ ] 5=rarely [ ] 6=No contact [ ]

6.2 Have you ever been trained on rainwater harvesting techniques for your farm? 1=Yes [ ] 2=No [ ]

6.3 If yes, state the extension agent/organization that provided the information………..

6.4 What were you trained on during the training exercise on rainwater harvesting? 1=Types of rainwater harvesting [ ] 2=Water harvesting structures [ ] 3=Purpose for rainwater harvesting [ ] 4=any other, please specify

6.5 Was the training beneficial to you? 1=Yes [ ] 2=No [ ]

6.6 If yes, how beneficial was the training? Rate below: 1=strongly agree [ ] 2=Agree [ ] 3=Not sure [ ] 4=Disagree [ ] 5=strongly disagree [ ]

Section 7: Membership to a social group

7.1 Are you a member of rainwater harvesting group? 1=Yes [ ] 2=No [ ]

7.2 If Yes, which one…………..

7.2.1 What are the main benefits of social group membership to rainwater harvesting?

7.3 Have your group received funding from any NGOs or County government programs on rainwater harvesting? 1=Yes [ ] 2=No [ ]

7.4 If yes, state……………………

7.5 Where do you access credit from? 1=Banks [ ] 2=Sacco [ ] 3=Family members [ ] 4=Friends [ ] 5Farmer groups [ ] 6=Micro finance institution [ ] 7= others specify

7.6 Any other comment/ observation…………………………………