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ORIGINAL ARTICLE

Determinants for rainwater harvesting adoption: a case study of smallholder farmers in Murang'a County, Kenya

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Abstract
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. Drawing on data from a cross sectional survey of 384 household heads (HH), the research study explored the determinants for rainwater harvesting among smallholder farmers in Murang'a County, Kenya. Multistage random sampling technique was employed during the survey using KOBO collect software for data collection. The findings revealed that socio-economic, socio-demographic and institutional factors significantly influenced the adoption of rooftop RWH, mulching, terraces, infiltration pits, retention ditches, water bunds, water pans, dams, furrows, negarims and deep ploughing among HH in Murang'a County. The multivariate probit model results showed that household head's access to credit facilities, land ownership, age, level of income, education level, gender, family size, source of income, membership to farmers' groups and access to training services positively influenced rainwater harvesting (RWH) adoption. Similarly, HH membership to farmers group(s) had merits including: social ties, source of information and source of credit which were also key determinants to RWH adoption in the area. The findings of the present study recommends the relevant stakeholders to carry out training to HH on RWHTs, creation of awareness among youths on merits for RWH adoption, encourage HH to join farmers' groups and encourage partnership with credit facilities in RWHTs adoption among HH in the region. Results of the present study provide valuable insights into the determinants for rainwater harvesting among smallholder farmers in Murang'a County which can be used to inform policy and practice for widespread adoption.

Keywords Agricultural water harvesting · Multivariate probit model · Rainwater harvesting technologies · Smallholder farming · Socio-demographic determinants · Socio-economic determinants

Introduction

Water is a critical resource in environmental sustainability, agricultural production as well as for improved livelihoods (Motho et al. 2022; Nicholas and Ukoha 2023). Water stress has been a menace to increased agricultural production in Sub-Saharan Africa (Kpadonou et al. 2017). The major cause of this is climate variability. Most Sub-Saharan countries are dependent on rain-fed agriculture hence are more vulnerable to increased climate related poverty in the region (Bitok et al. 2023). Coping mechanisms have been put in place through increased adoption of land and water management practices such as soil and water conservation measures (Mango et al. 2018). These mechanisms are interventions or steps to enhance increased resilience to the prevailing climate changes experienced globally. They include but not limited to soil and water management structures. These practices are further known as climate smart agricultural practices (CSA). Intensification of agricultural technologies is one of the best mechanism to enhance increased agricultural water management which positively improve resilience to prolonged dry spells and droughts in water challenging regions (Bitok et al. 2023).

Rainwater harvesting (RWH) systems have been adopted in Asian countries such as India, Thailand, Korea and China (Black et al. 2012). Both ex-situ and in-situ water harvesting

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systems have been highly adopted in African countries including Nigeria (García-Ávila et al. 2023; Nicholas and Ukoha 2023), Tanzania (Timothy et al. 2022), Ethiopia (Kifle et al. 2022), Ghana (Theis et al. 2018) and South Africa (Mango et al. 2018). Previous studies have demonstrated that smallholder farmers in East African countries including Kenya have been greatly affected by climatic changes as compared to other countries in the world (Timothy et al. 2022) hence are expected to adopt RWH.

According to World Bank (2016), Kenya's agricultural productivity as well as GDP has been on a decline due to climate change vulnerability and large dependence on rainfed agriculture at 98%. 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). Erratic, inadequate and reduced rainfall is the major cause for declined livestock and agricultural productivity in Kenya including Murang'a County (Ngure et al. 2021). Climatic shocks experienced in Murang'a County include: prolonged droughts and dry spells, drying out of rivers, floods and unpredictable rainfall (Maindi et al. 2020). This has been a constraint for both crop and livestock production. Adoption of rainwater harvesting is a climate smart agricultural practice (CSAP) to increase water availability and reduce soil erosion from rainwater runoff among smallholder farming systems in Murang'a County (Mwaura et al. 2018; Röhrig et al. 2017; Maindi et al. 2020). Previous studies have documented rainwater harvesting as one of the best alternative measures to adapt to climate change in Kenya (Odhiambo et al. 2021, 2022). This means that, RWH adoption helps in climate change mitigation through reduced climate change shocks in the region. Consequently, RWH adoption depends on underlying factors including socio-economic, social demographic, institutional, government policies and environmental conditions (Jan 2020; Mairura et al. 2021; Mpatane et al. 2016; Musa et al. 2022; Nabwire 2020). Previous studies done in Murang'a County have not documented the determinants influencing surface and roof top rainwater harvesting techniques. This study aimed to bridge this gap by establishing the determinants that influence rain water harvesting techniques among smallholder farmers in Murang'a County, Kenya.

Material and methods

Study area

The study was carried out in Murang'a County, central parts of Kenya. Murang'a County covers a land area of 2524.2 Square kilometers (KNBS 2019). It is located at a longitude of 36° 37° 27′E and between a latitude of 0° 34′ and 10 ° 7′S (Maindi et al. 2020). The study area map is as shown in Fig. 1 below:

It has a bi-modal rainfall distribution experiencing both long rains and short rains between mid-March to the end of May and from October to December, respectively (Maindi et al. 2020). However, Murang'a County has different soil types depending on the underlying geologic conditions of both basement system of rocks and volcanic rocks (Bitok et al. 2023). The principal soil type in the County is humic Nitisols. They are characterized by a dusky red to reddish-brown in color, extremely deep, well drained with a humic topsoil and a friable clay (Kalungu et al. 2013). The County receives an annual rainfall ranging between 1400 and 1600 mm. The County's temperature varies with altitude. The maximum annual temperature ranges in between 26 and 30 ℃ while the mean annual temperature conditions ranges between 14 and 18 (Bitok et al. 2023). The main agricultural activity in the County is mixed farming. Agriculture has increasingly anchored County's economy (CIDP 2018; Maindi et al. 2020). The County lies between altitudes of 914 m above sea level (a.s.l) from the east and 3353 m a.s.l from the west along slopes of Aberdare Mountain (Maindi et al. 2020). According to the Murang'a County Integrated Development Plan, 2018 (CIDP 2018) and Maindi et al., (2020) both food crops, cash crops and horticultural crops are grown in the area at 80% among the residents. Livestock production is also a popular agricultural practice in the County. The predominantly grown crops in the area include: maize, bananas, macadamia, tea, potatoes, kales, cabbages, avocados, coffee and improved fodder and pasture (Maindi et al. 2020). Kiharu Sub-County was purposively selected as the study area in the County. It is located in Murang'a East with three administrative wards namely: Murarandia, Mugoiri and Wangu. Physiographic conditions vary from steep slopes to gentle slopes.

Murang'a East is located in the central region of the County with sub-tropical climatic conditions (Bitok et al. 2023). The area has a combination of agro-ecological zones; upper midlands (UM1–UM5) (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 water harvesting techniques 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 2019). Kiharu Sub County covers an area of 169.4Km^2 (KNBS 2019). The Sub-County was purposively selected since RWH projects such as water pans construction are implemented in the region under funded projects by County government development programs (CDPs) in partnership with non-governmental organizations such as National Agricultural and Rural Inclusive Growth Projects (NARIGP) and Upper Tana Natural Resources and Management (UTaNRMP).

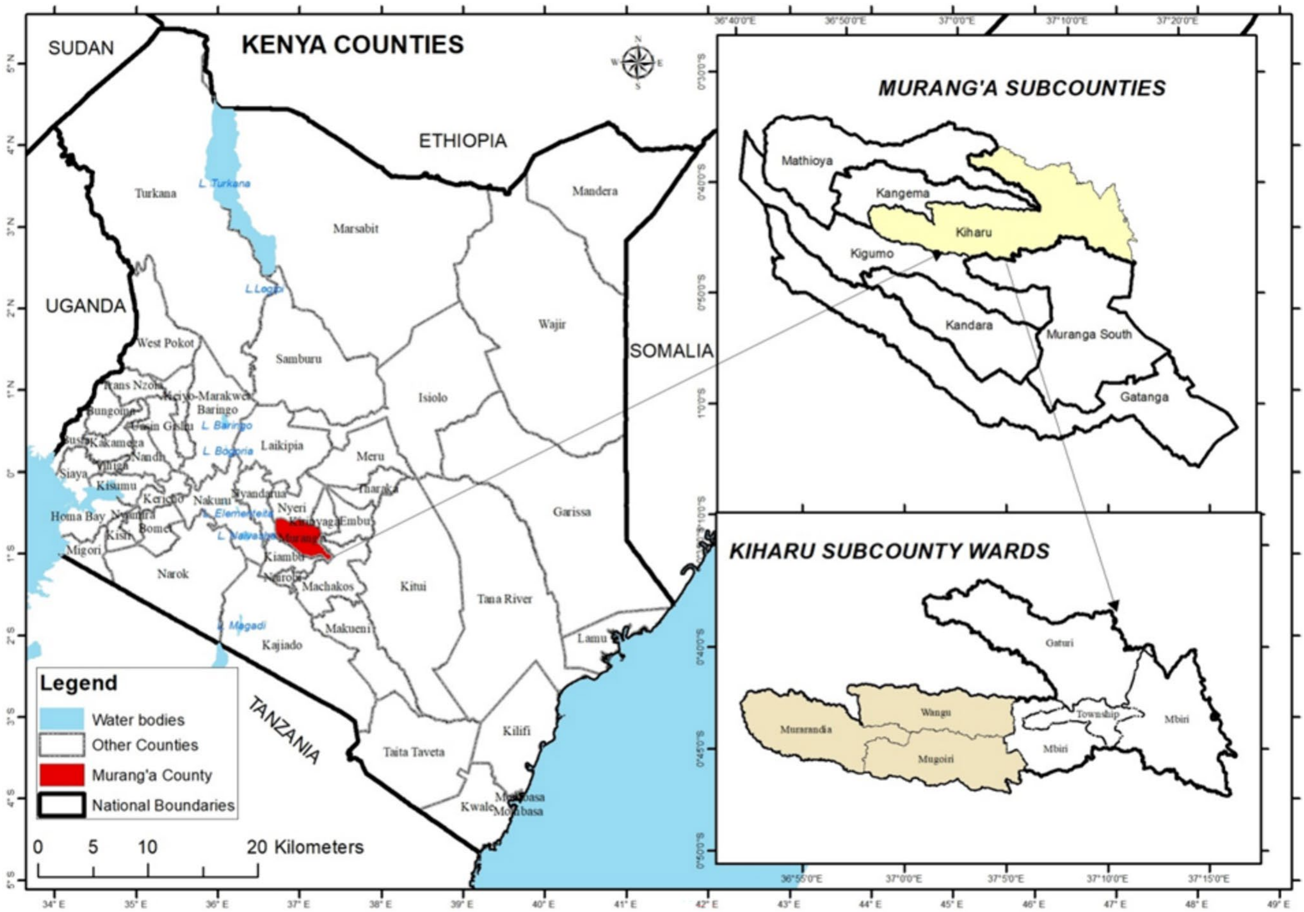


Fig. 1 Study location map. source: Author

Research design

To determine the RWHT and the crop and livestock enterprises adopted under the rainwater harvesting techniques (RWHTs), the study employed a cross-sectional survey. The survey was conducted through on-farm face to face interview. This was done among household heads from the three administrative wards. Two administrative locations from each ward were identified and one sub-location from each administrative location was randomly sampled where a one-time data collection exercise was done by four well-trained enumerators.

Sampling design

Multistage sampling technique was employed in this research study. Kiharu Sub-County was purposively sampled in the first stage. The second stage employed stratified sampling where the sample frame population was grouped into three administrative wards. The third stage was a random sampling of two administrative locations from each ward. The last stage employed a simple random sampling of households from one sub-location from 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) shown below:

$$n_0 = \frac{z^2 pq}{e^2} \tag{1}$$

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

To obtain a sample size of 384 household heads after below computation:

$$n_0 = \frac{(1.96^2)(0.50)(0.50)}{(0.50^2)} = 384 \text{ household heads}$$

Proportionate sample size distribution was done as per (Table 1) from two locations per ward and one sub-location from each administrative location depending on the sample frame obtained from Kiharu Sub-county Agricultural Offices.

Table 1 Households sample size for Kiharu Sub-County on RWH

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
Wangu	8, 685	124	Wanjengi	1,880	51	Wanjengi	1279	51
			Weithaga	2, 655	73	Kianderi	707	73
Total	**26,930**	**384**			**384**			**384**

Data collection

Data collection was based on a questionnaire that combined closed and open ended questions which were administered at household level and recorded by an enumerator using Kobo collect software. Pre-testing of the questionnaire and the Kobo collect app kit was done prior to data collection in Mugoiri ward to ensure smooth data collection exercise. Data was collected from all the three wards namely: Mugoiri, Murarandia and Weithaga. The interview was administered by four enumerators who were recruited prior to the data collection exercise and trained on the mobile data collection software (Kobo collect application). The interviews were conducted at household's level. During the interview, household heads (HH) were interviewed but in their absence a phone call was made by the enumerator to conduct the interview or the most elder member of the household assisted the enumerator to fill in the questionnaire. The interview focused on evaluating the key determinants for different rainwater harvesting techniques adopted among smallholder farmers in Murang'a County.

Data analysis

The collected data was organized and cleaned in excel data sheet and exported for analysis using Statistical Package for Social Sciences (SPSS) software version 25 and Stata 14.2. Descriptive statistics was done to determine the extent of rainwater harvesting techniques adoption as well as key social, economic and the institutional factors that determines adoption rate of different RWH techniques. Cross tabulations and frequencies obtained from the analysis was used to develop the relationships between the different rainwater harvesting techniques and the HH characteristics as the key determinants for adoption. Furthermore, a multivariate probit model (MVP) was used for analysis as recommended by Belachew et al. (2020). This model was the most appropriate because different RWHTs influenced by different factors adopted by a household head were simultaneously evaluated and allowed the error terms to correlate. Since the study was based on more than two RWHT, a household may select one or more RWH technologies due to different unknown and unobservable characteristics of the household heads that were sampled and their farms. Therefore, this model was appropriate to avoid statistical bias and inefficiency in estimation. This model is as expressed as shown below:

$$Y_{ij} = X_{ij}\beta_{ij} + \varepsilon_{ij}$$

where Y_{ij} represents adoption of rainwater harvesting technologies (terraces, mulching, water bunds, negarims, water pans, retention ditches, infiltration pits, furrows and deep ploughing) by the household head, i was the household id (1, 2, 3, 4…384 households), j was the key determinants for rainwater harvesting technologies (landownership, age, education level, credit access, gender, family size, source of income, membership to farmers' groups and access to training services), x was the vector of the predictor variables, β is the vector of the unknown variables/parameters, ε is the normally distributed unobserved error term.

Results and discussion

Rainwater harvesting adoption in Kiharu Sub County, Murang'a County

This study found diverse adoption of rainwater harvesting techniques (RWHTs) among HH in the study area (Table 2). Surface RWH and rooftop water harvesting were the principal techniques commonly adopted in Murang'a County. In addition, some of the HH in Kiharu Sub-county relied on other main sources of water such as river, piped water, borehole, wells and springs at17.45%, 64.84%, 11.98%, 3.91% and 1.82% respectively (see Fig. 2).

Rooftop water harvesting was highly adopted at a rate of 93.23%. On the other hand, surface rainwater harvesting technologies (SRWHTs) were adopted as tabulated in Table 2.

Table 2 Intensity of adoption for rainwater harvesting techniques among household heads (N = 384)

RWHTs	Adopters	
	Frequency	Percentage
Rooftop RWHT	358	93.23
Surface RWHTs		
Terraces	208	54.17
Infiltration pits	309	80.47
Mulching	195	50.78
Negarims	43	11.20
Furrows	260	67.71
Retention ditches	88	22.92
Water pans	67	17.45
Water bunds	21	5.47
Dams	1	0.26
Deep ploughing	259	67.45

Infiltration pits were highly adopted at 80.47%. The study established that infiltration pits technique was the most highly adopted type of SRWHT among household heads in this region. Furrows and deep ploughing were adopted by 67.71% and 67.45% of the HH respectively. The study found that about half (54.17%) and (50.78%) of the HH adopted terraces and mulching respectively. Retention ditches, water pans techniques and negarims were lowly adopted in the region at 22.92%, 17.45% and 11.20% respectively (Table 2). Household heads adopted water bunds at 5.47% while, dams were least adopted in the region at 0.26%. 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.

Rainwater harvesting techniques were adopted for various reasons which included: livestock production, crop production and domestic purposes while some adopted for a combination of the three stated reasons at 25.78%, 85.94%, 73.44% and 19.79% respectively (Table 3). 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.

Table 3 Reasons for RWH among HH in Kiharu Sub County, Murang'a County

Reason	Frequency	Percentage
Domestic purposes	282	73.44
Livestock production	99	25.78
Crop production	330	85.94
All of the above stated reasons	76	19.79

Rainwater harvesting adopters used different water storage facilities such as water pans/ponds, water tanks, drums and jerry cans in Murang'a County at 18.49%, 78.39%, 25.78% and 50.52% respectively (Fig. 3). This pointed out that most of the HH harvested rain water using water tanks and least harvested rain water using water ponds. 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.

Characteristics of RWH adopters in Kiharu Sub County, Murang'a County

The study interviewed 384 household heads. Figures 4, 5, 6, 7, 8, 9, 10, 11 and 12. shows the socio-demographic and socio-economic characteristics for rain water harvesting adopters in Kiharu Sub-County, Murang'a County.

Socio-demographic characteristics

Gender

The sampled HH constituted 71.35% male while 28.65 were female (Fig. 4). This means that male-headed households in Murang'a County highly adopted rain water harvesting technologies than female-headed households. This could be due to the gender disparities in Kiharu Sub County.

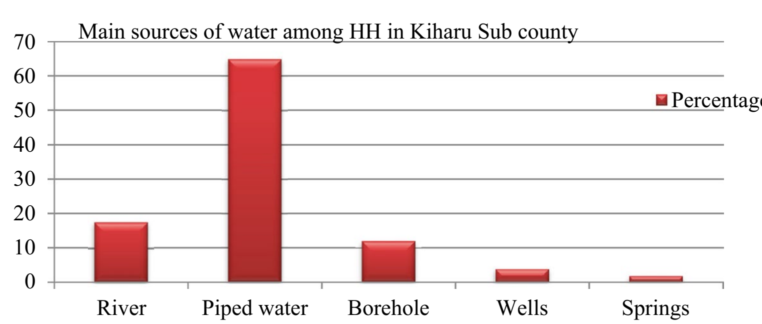


Fig. 2 Main sources of water among HH in Kiharu Sub County, Murang'a County

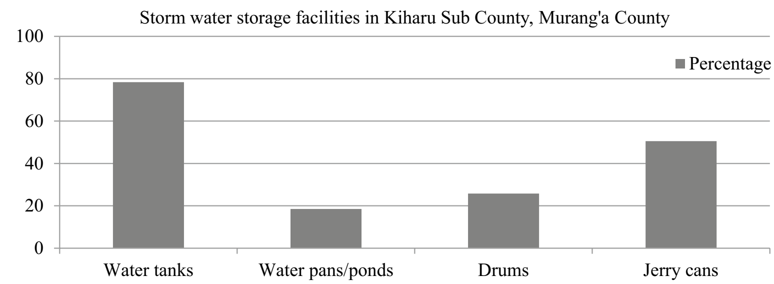


Fig. 3 Storage facilities for rooftop harvested rainwater in Kiharu Sub County, Murang'a County

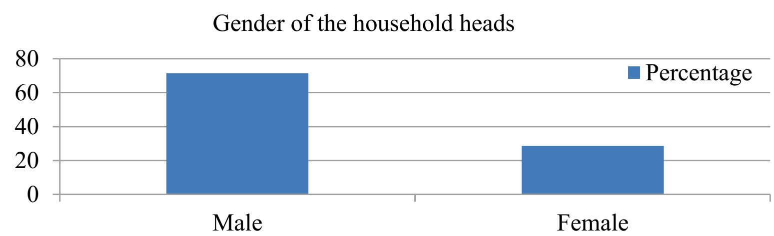


Fig. 4 Gender of the household heads in Kiharu Sub County, Murang'a County

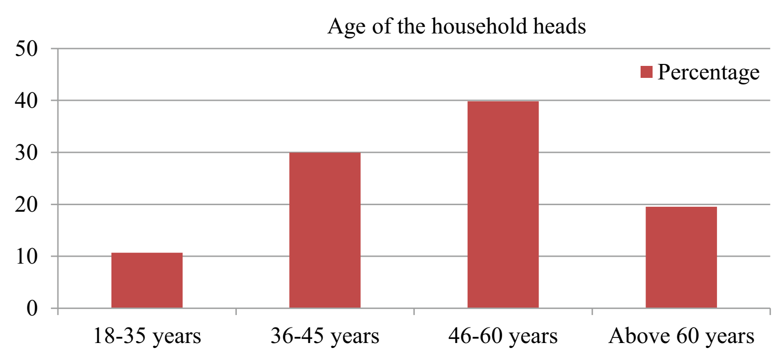


Fig. 5 Age of the household heads in Kiharu Sub County, Murang'a County

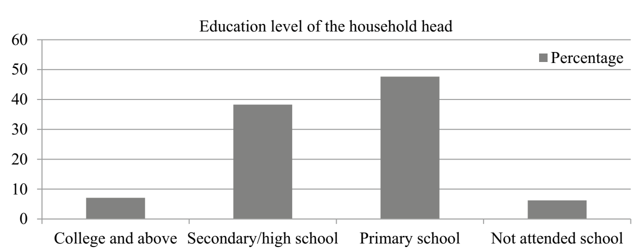


Fig. 6 Education of the household heads in Kiharu Sub County, Murang'a County

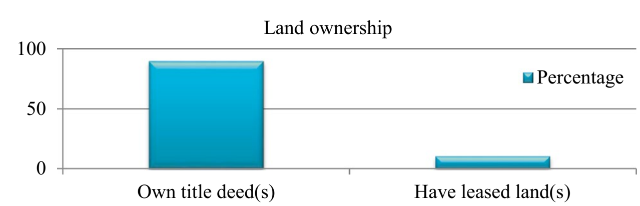


Fig. 8 Land ownership among household heads in Kiharu Sub, County, Murang'a County. Sources and levels of income among household heads

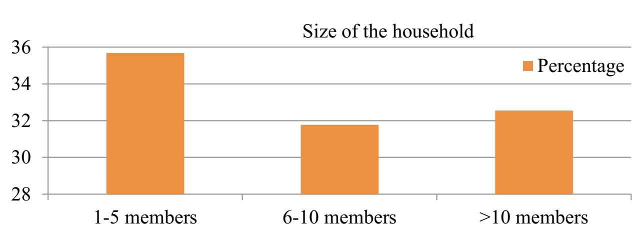


Fig. 7 Size of the households in Kiharu Sub County, Murang'a County

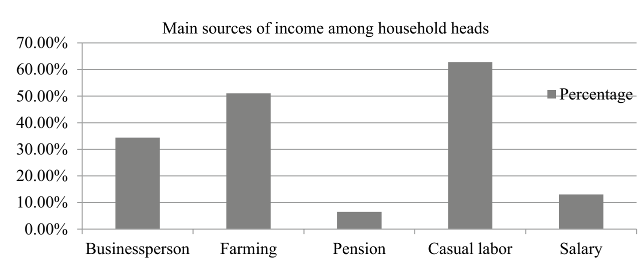


Fig. 9 Sources of income among household heads in Kiharu Sub County, Murang'a County

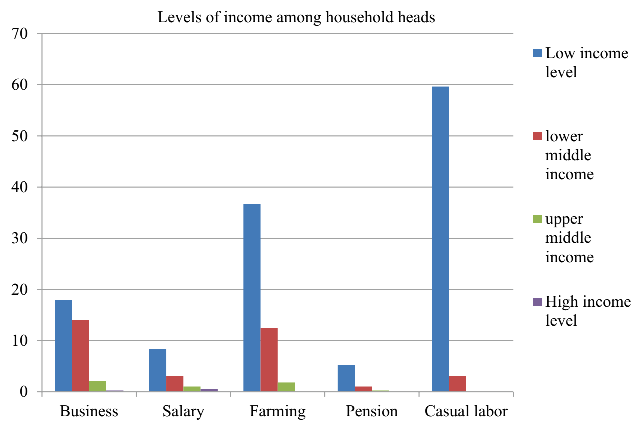


Fig.10 Levels of income among household heads in Kiharu Sub County, Murang'a County

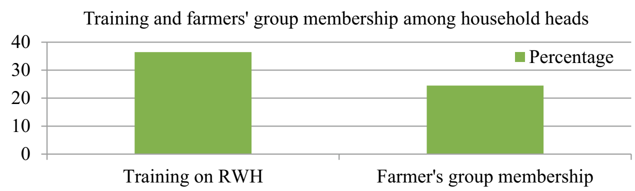


Fig. 11 Training and farmers' group membership among household heads in Kiharu Sub County, Murang'a County

Age of the household heads

Most of the HH (39.84%) interviewed ranged between 46 and 60 years old, 29.95% ranged between 36 and 45 years old, 19.53% were above 60 years old while only 10.68% were youths ranging between 18 and 35 years old (Fig. 5). This showed that most of RWH adopters ranged between 46 and 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 lowly adopted these technologies in the area.

Education level of the household heads

Most of the HH interviewed were educated with the least educated having attended a primary school. 47.66% of the HH attended up to a primary level, 38.28% had a highest education level at a secondary level while only 7.81% had attended a tertiary institution (Fig. 6). 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.

Size of the households

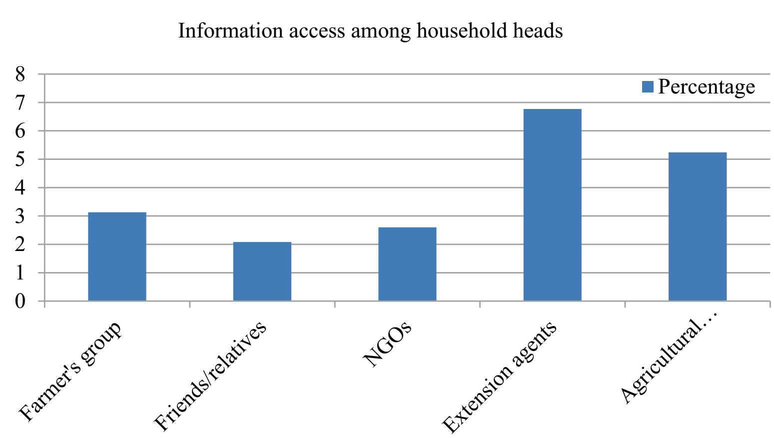
Most of the households had a household size ranging between one to five household members at 35.68% while 31.77% of the households had six to ten members and 32.55% of the households had more than ten members (Fig. 7). This revealed that households with between one to five members highly adopted water harvesting technologies in this region as compared to households with between six members and above.

Socio-economic characteristics

Land ownership

Most of the household heads had more secured land with title deeds at 89.58% while the rest had leases lands at

Fig. 12 Sources of information on RWH adoption among household heads in Kiharu Sub County, Murang'a County



10.42% (Fig. 8). 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.

The HH interviewed had different sources of income including farming, businesspersons, pension, casual labor and salaried persons at 51.04%, 34.38%, 6.51%, 62.76% and 13.02% respectively.

Levels of income varied widely among HH in Kiharu Sub-county. Household heads who earned their income from owned business varied based on their scale of business and success. Four levels of income were adopted as per the WorldBank (2023) rating. These levels were low income earners, lower middle income, upper middle income earners and high income earners. The low income HH earned a relatively modest amount that was slightly above or close to the poverty line in Kenya. The middle income household heads earned a relatively average amount of income while, the high income HH earned a substantial amount of money relatively well above the country's average which meant that the individuals had a higher standard of living as well as greater financial resources. Low income earners earned Kenyan Shillings (Ksh) fifteen thousand and below, lower middle income earners earned between Kenyan Shilling sixteen thousand to Kenyan Shillings fifty thousand while, the upper middle income earners earned between Kenyan Shillings fifty one thousand to Kenyan Shillings one hundred thousand. Classification of HH on levels of income is as shown in Fig. 10.

Access to training and farmers' group membership

Most of the HH had no access to training services for adoption of rainwater harvesting techniques in Murang'a County. However, only 36.46 had access to training on rainwater harvesting adoption and inventions (Fig. 11). 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. Only a few (24.48%) (Fig. 11) of the HH were a member of at least one farmers' group who benefited differently as shown in (Table 5).

Information access among household heads

In addition, only a few of the HH had access to information from various sources. Household heads who obtained information from extension agents, non-governmental organization, friends and relatives and farmer's groups were: 6.77%, 2.60%, 2.08% and 3.13%, respectively (Fig. 12). These results agree with the results of Bitok et al. (2023) who found that farmers in Kiharu Sub county obtain information on CSA technologies from Extension agents, non-governmental organizations (NGOs) and agricultural shows.

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. Most of the HH in the region were members of Saccos at 30.5% while the rest were members of farmers' group(s), banks and microfinance institutions at 24.48%, 10.7% and 14.6% (Fig. 13). 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 agree with the results found by Bitok et al. (2023) and Ngango & Hong (2021) in Murang'a County, Kenya and Rwanda respectively.

Factors influencing adoption of RWHTs in Murang'a County

Table 4 below shows multivariate probit model estimates for the factors that influenced rainwater harvesting techniques in the study area. The results exhibited both positive and negative influence to adoption of RWHTs. These were the key determinants for adoption of water harvesting technologies in Murang'a.

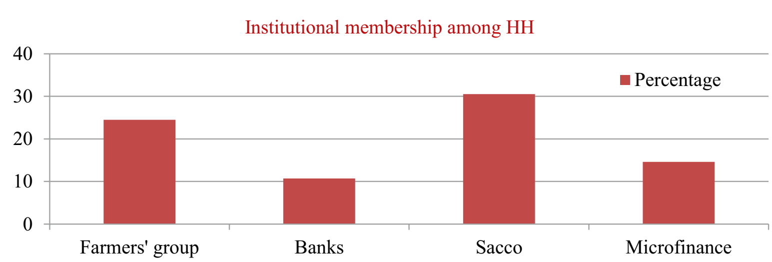


Fig. 13 Institutional membership among HH in Kiharu Sub County, Murang'a County

Table 4 Determinants for rainwater harvesting techniques among smallholder farmers in Murang'a County, Keya

Variables	RTH	T	IP	M	N	W	F	RD	DP
	Coef Std. E	Coef Std. E	Coef Std. E	Coef Std. E	Coef Std. E	Coef Std. E	Coef Std. E	Coef Std. E	Coef Std. E
Socio-demographic factors									
Gender	0.19 (0.29)	**– 0.59*** (0.17)**	– 0.04 (0.20)	– 0.04 (0.17)	– 0.13 (0.24)	**– 0.57* (0.23)**	– 0.01 (0.17)	**0.37* (0.18)**	– 0.29 (0.17)
Age	0.25 (0.16)	0.20* (0.10)	0.16 (0.12)	0.05 (0.10)	0.01 (0.14)	– 0.02 (0.12)	0.24* (0.10)	0.17 (0.11)	0.19 (0.10)
Education	**0.32* (0.18)**	– 0.11 (0.11)	**– 0.45** (0.14)**	– 0.17 (0.11)	– 0.25 (0.14)	– 0.05 (0.12)	**– 0.24* (0.11)**	**– 0.26* (0.11)**	– 0.21 (0.11)
Household size	0.11 (0.15)	– 0.06 (0.10)	0.14 (0.11)	**0.19* (0.10)**	0.19 (0.14)	0.18 (0.12)	0.13 (0.10)	0.04 (0.11)	– 0.01 (0.10)
Distance to source of water	– 0.01 (0.13)	**0.19* (0.08)**	0.11 (0.10)	0.05 (0.08)	0.05 (0.11)	**0.15* (0.09)**	0.10 (0.09)	0.10 (0.09)	– 0.04 (0.10)
Socio-economic factors									
Land ownership	0.61 (0.32)	– 0.16 (0.24)	**0.54* (0.24)**	**0.53* (0.24)**	– 0.05 (0.32)	– 0.12 (0.28)	**0.69** (0.23)**	0.55 (0.30)	**0.54* (0.23)**
Group membership	– 0.10 (0.30)	**0.39* (0.17)**	0.33 (0.21)	0.16 (0.17)	0.23 (0.21)	0.27 (0.19)	**0.36* (0.18)**	**0.36* (0.18)**	**0.49** (0.18)**
RWH Training	**0.72* (0.29)**	0.26 (0.15)	– 0.04 (0.17)	0.26 (0.15)	**0.41* (0.20)**	0.10 (0.18)	0.11 (0.15)	**0.35* (0.16)**	0.01 (0.15)
Source of income									
1. Business person	0.26 (0.28)	0.16 (0.17)	0.15 (0.20)	0.10 (0.17)	0.36 (0.22)	– 0.23 (0.20)	0.18 (0.18)	0.33 (0.18)	**0.36* (0.18)**
2. Farming	– 0.26 (0.25)	**0.35* (0.16)**	0.25 (0.18)	**0.32* (0.15)**	– 0.05 (0.20)	– 0.03 (0.18)	0.10 (0.16)	0.08 (0.16)	0.23 (0.16)
3. Pension	**– 1.10* (0.47)**	0.63 (0.35)	0.84 (0.56)	0.01 (0.33)	0.43 (0.37)	**– 0.85* (0.41)**	– 0.35 (0.33)	– 0.34 (0.35)	0.01 (0.33)
4. Casual labor	– 0.08 (0.27)	– 0.01 (0.17)	0.31 (0.20)	0.14 (0.17)	0.17 (0.22)	**– 0.41* (0.20)**	0.30 (0.17)	0.03 (0.18)	0.27 (0.17)
Institutional factors on credit access									
Sacco	– 0.45 (0.26)	– 0.13 (0.17)	0.37 (0.21)	**0.46** (0.17)**	0.23 (0.21)	**0.66*** (0.19)**	0.02 (0.17)	0.28 (0.18)	0.26 (0.17)
Micro-finance	0.10 (0.40)	– 0.21 (0.23)	0.16 (0.30)	0.29 (0.23)	– 0.12 (0.31)	0.49 (0.27)	0.17 (0.24)	**– 0.57* (0.25)**	0.10 (0.24)
Farmer's groups	0.18 (0.27)	**– 0.48** (0.18)**	0.05 (0.21)	0.23 (0.20)	0.02 (0.24)	0.20 (0.21)	– 0.04 (0.18)	0.10 (0.20)	– 0.17 (0.18)

Standard errors in parentheses

Legends *RTH* rooftop rainwater harvesting technique, *T* terraces, *IP* infiltration pits, *M* mulching, *N* negarims, *W* water pans, *F* furrows, *RD* retention ditches, *DP* deep ploughing

*$p < 0.05$,

**$p < 0.01$,

***$p < 0.001$ Multivariate probit (SML, # draws = 5), Number of observation = 384, Wald chi2(135) = 262.04, Log likelihood = – 1495.326, Prob > chi2 = 0.0000, Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho81 = rho91 = rho32 = rho42 = rho52 = rho62 = rho72 = > rho82 = rho92 = rho43 = rho53 = rho63 = rho73 = rho83 = rho93 = rho54 = rho64 = rho74 = rho84 = rho94 = rho65 = rho75 = rho85 = > rho95 = rho76 = rho86 = rho96 = rho87 = rho97 = rho98 = 0: chi2(36) = 274.946 Prob > chi2 = 0.0000

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 (Table 4) in Murang'a. 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. 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 at 1% significance level (Table 4). 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 at 5% level of significance (Table 4). This exhibited that increase in age of the HH increased adoption of terrace and furrows techniques 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 techniques (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 youths aged eighteen to thirty five years (Fig. 5). 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 techniques in Murang'a. Household size exhibited a positive significant relationship to increased adoption of mulching surface water harvesting technique (Table 4) at 5% significance level. This suggested that increase by one member in a household positively influenced an increase in adoption of mulching as a water harvesting technique. Increased adoption of these techniques was due to increased human capital from the increased household size thus adequate labor for adoption of mulching and deep ploughing techniques (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 techniques adoption. Source of water significantly and positively influenced the adoption of terraces and water pans (Table 4). The results of this study agree with the findings of Mango et al. (2018) and Ngango and Hong (2021) who stated 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.

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 techniques. This suggested that household heads who were members to a farmers' group significantly influenced an increase in adoption of deep ploughing by 0.488. Further, the results showed that membership to farmers' group(s) positively increased the adoption of terraces, furrows and retention ditches at 5% significance level by (Table 4). 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 (Table 5). 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.

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. 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).

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 their 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 (Table 4). These findings implied that household heads who owned their land either by owning a title deed or by leasehold terms had a higher likelihood of intensifying multiple water harvesting techniques 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 techniques in the current study (Table 4). Education of the household head negatively influenced adoption of infiltration pits at 1% level of significance, furrows ($p < 0.05$) and retention ditches ($p < 0.05$). Increased 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 techniques among households. However, education had a positive significant influence to increased adoption of rooftop rainwater harvesting at 5% level of significance (Table 4). This suggested that highly educated households 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 techniques than non-educated farmers.

Table 5 Correlation matrix

Variables	(1)	(2)	(3)	(4)
(1)	1.000			
(2)	0.260**	1.000		
(3)	0.205**	0.294**	1.000	
(4)	0.336**	0.330**	0.697**	1.000

Benefits for HH group membership

Spearman rho = 0.697

1 = trainings 2 = credit access 3 = social ties 4 = information access on rainwater harvesting

Different sources of income exhibited both negative and positive influence to adoption of different RWHTs in Murang'a (Table 4). 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 techniques at 5% level of significance. Household heads who relied their source of income as businesspersons had propensity to increase the adoption of deep ploughing by 0.360 while, HH who relied on farming as their main source of income had a likelihood of adopting terraces and mulching water harvesting techniques. 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 RWHT adoption (Table 4). 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 techniques showed a positive significant influence to adoption of water harvesting techniques in Murang'a County (Table 4). 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 (Table 4). Similar observation were made by Belachew et al. (2020), Kimani et al. (2015) and Mairura et al. (2021) who stated that access to training increased RWH intensification in Southwest Ethiopian highlands, Makueni County in ASALs of Kenya and Central highlands of Kenya, respectively.

Institutional determinants

The principal institution determinants in this study were sources of credit among HH in Kiharu Sub County (Fig. 1). 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 (Table 4). Access to credit increased the level of adoption for mulching and water pans techniques. Mekuria et al. (2020); Gichangi and Gatheru (2018); Ngango and 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.

Conclusion and recommendation

The study findings affirmed that socio-economic, institutional and socio-demographic characteristics are key factors for rainwater harvesting adoption among smallholder farmers in Murang'a County, Kenya. The results of multivariate probit model depicted that household head characteristics were significant for different RWHTs adoption behavior. Consequently, other variables such as access to credit, training on different RWHTs adoption, membership to farmers' groups, sources of income, land ownership were significant socio-economic determinants in the model. Age, gender, household size and distance to source of water were also significant socio-demographic determinants for WHTs in the county. However, the negative signs in different factors such as gender, education, sources of income such as pension and casual labor, credit access sources such as micro finance and farmer's group indicated an inverse relation to RWH adoption as they negatively influenced water harvesting techniques adoption. Further, the results suggest that policy interventions targeting these determinants have the potential to increase RWH adoption among smallholder farmers in Murang'a County. In conclusion, the results of the present study further recommend the following: local government and non-governmental organizations implementing RWHTs in the area should encourage household heads to join social groups for increased social networking and interconnectedness which will promote RWH adoption. This will positively promote the adoption rate due to increased awareness and exposure to more training for the different water harvesting techniques. Further research may be done in future to find out why education level, gender, income sources and credit access determinants negatively influenced rainwater harvesting adoption. The County government and NGOs in partnership with the financial institutions should create awareness on benefits of credit borrowing for RWH adoption as well as further research be done on reasons for low adoption of dams, water bunds, retention ditches and water pans water harvesting technique in Murang'a County.

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Author contributions The main idea of this research paper was generated by the corresponding author Francis Irungu Itemo. Later the author conceptualized the study, carried out data collection, data analysis, interpreted data and wrote the first version of the manuscript and more comments were added by the second and third authors respectively. Dr. Rebecca Yegon was the second author who took part in study conceptualization, ideas generation, data interpretation and commented on the second version of the manuscript. Dr. Muniale Faith Milkah took part in idea generation, study conceptualization, data interpretation and contributed in making comments to the final version of the manuscript.

Data availability All the relevant data for this study was included in the paper and is available upon reasonable request.

Declarations

Conflict of interest All authors declared no personal or any financial competing interests for the research work reported in this study.

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