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Adoption of water harvesting technologies among agro-pastoralists in semi-arid rangelands of South Eastern Kenya

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Abstract

Background: The arid and semi-arid lands experience inherently unpredictable rainfall and frequent droughts, which are exacerbated by climate change. This consequently leads to deterioration of land resources, and eventually forage and water shortages that negatively impact livestock productivity. In Kenya, development and government agencies have been supporting on-farm adaptation strategies such as water harvesting conservation structures to cope with climate hazards that affect agricultural production and food security in agro-pastoral and pastoral systems. The various water harvesting structures that have been promoted include Zai pits for growing crops and trees, water pans and shallow wells for livestock and domestic use, as well as for irrigation. However, the impact of such interventions with regard to improvement of range productivity and therefore welfare of agro-pastoral and pastoral communities has not been felt owing to low adoption rate by households.

Results: This study determined social, economic and institutional factors influencing the adoption of water harvesting technologies by households in pastoral areas of Tana river County of Kenya. The data was collected through household survey, focus group discussions and key informant interviews. The results show that access to extension services and training, level of monthly income, main source of livelihood, land tenure, membership in social groups and availability of active farm labor significantly influenced the adoption of water harvesting structures.

Conclusion: Pastoralists therefore need to be mobilized and trained on how to construct and use water harvesting structures and sensitized on the potential socioeconomic benefits of adopting them.

Keywords: Drylands, Water harvesting, Adaptive strategies, Pastoralism

Introduction

Rangelands make about 40%of the global land surface (Sutie et al. 2005) and constitute approximately 69% of the world's agricultural land (FAO 2009). They are important habitats for wild flora and fauna as well as for domestic livestock (Osano et al. 2013). Rangelands are predominantly used for pastoralism, which is a low external input subsistence system characterized by extensive livestock production (Wasonga 2009). Pastoralism is grounded on strategic exploitation of resources that are non-uniformly distributed in space and time (Wasonga et al. 2003). The spatio-temporal variability in water and pasture availability influences mobility and settlement patterns of pastoral communities leading to the development of pastoralism as the most suitable economic activity in the arid and semi-arid areas (Galvin 2009).

Pastoralists and agro-pastoralists are confronted with a variety of risks that constantly disrupt their livelihoods and devastate assets (Wasonga 2016). These risks, coupled with limited and increasingly ineffective

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risk management options, underlie vulnerability in pastoral systems. Some of the challenges facing the pastoral communities include land tenure changes, diminishing grazing resource base and frequent droughts which undermine pasture and livestock productivity (Gao et al. 2009). Recurring droughts have a direct negative impact on natural pasture growth, often resulting in lack of fodder and consequent economic loss for livestock that may reach disaster levels (Downing and Bakker 2000).

Traditional drought-coping mechanisms of both pastoralists and agro-pastoralists, such as splitting the herd in various groups spread over the community under the care of relatives seem to have become less effective due to socioeconomic and political changes. In this context, drought contingency planning is gradually receiving more attention as an important strategy to lessen the impact of droughts (Wilhite 2000). Such planning can occur both at government and at household or pastoral enterprise levels. It invariably involves the formation of reserves, whether of pasture or water (Bruins 2000) in the wake of climate change and variability.

The agropastoral communities' capacity to cope with and adapt to the changing conditions in climate has further been compounded by the wider social and institutional contexts of pastoral systems. Human and livestock population growth has increased pressure on natural resources in pastoral areas (Lutta et al. 2020). This, coupled with the loss of land and water resources to non-pastoral use and interruption of migration routes, leaves livestock keepers with fewer accessible pasture and water resources (Lutta et al. 2019), and eventually impairs pastoralists' traditional drought coping strategies. In response to these challenges, development and government agencies have been promoting various coping and adaptation strategies, in addition to pastoralists and agro-pastoralists own initiatives to enhance production and food security in the face of extreme climatic trends in the arid and semi-arid rangelands of Kenya. A number of these adaptation strategies are specific to certain value chains, while others cut across different value chains, among them, water harvesting initiatives aimed at improving rangeland productivity and availing water for livestock, domestic and irrigation use.

Water harvesting is especially crucial for the arid and semi-arid areas that not only experience unpredictable rainfall, recurrent droughts, but also heavy torrents and floods when it rains. Runoff harvesting enhances water security given that a significant part of tropical rains is normally lost as runoff, potentially causing erosion (Kalungu et al. 2015). It is important in harnessing otherwise transient flood water for use during extended dry seasons and drought, as well as in controlling soil erosion. As observed by Sidibe (2005) and Matata et al. (2010), harvesting of water which would otherwise flood off is a case of preparedness and mitigation planning, as the presence of water harvesting structures can make pastoral households better prepared to mitigate drought by managing the reduced input of rainwater more intensively and efficiently.

In Kenya's arid and semi-arid lands (ASALs) various water harvesting techniques, including construction of water harvesting structures such as Zai pits, water pans and shallow wells have been used to capture the little rainfall received in these areas to support pasture and crop production (GoK 2014; Kalungu et al. 2015). These techniques are aimed at preventing soil erosion by reducing runoff especially in sloppy terrain of rangelands and improve infiltration of water into the soil (Oweis 2016; Appels et al. 2016). Tana River County of Kenya is one of the ASALs where water harvesting technologies have been promoted as drought mitigation strategy, both for the purpose of soil and water conservation, and harnessing of run-off for livestock and domestic use, especially during drought periods. However, the impact of these interventions is not yet fully felt due to low adoption of the technologies by households. This study sought to determine socio-economic factors affecting the adoption of water harvesting structures aimed at harnessing run-off to improve pasture production in semi-intensive agro-pastoral systems of Tana River County of Kenya.

Methodology

Study area

The study was done in Tana River County (Fig. 1) which covers 38,682 km^2 and is located in Kenya's coastal region. One of the important natural resources in the county is River Tana, Kenya's largest river, which flows through the county as it drains into the Indian Ocean. River Tana forms the Tana River Delta wetland that covers about 1300 km^2 and supports more than 100,000 inhabitants (Leauthaud et al. 2013). The county is largely semi-arid rangeland, receiving low and erratic convectional rainfall. The average annual rainfall is about 280–900 mm (GoK 2014). Rainfall distribution is bimodal with the long rains occurring in April to May and, the short rains in October to December. The riverine and delta areas are highly vulnerable to flooding in years with high precipitation. The temperature of the area ranges from a minimum of 23 °C to a maximum of 38 °C (KIRA 2014).

Despite the dry conditions, agriculture is the main income-earning activity in the county, contributing roughly 82% of the households' income (GoK 2013). However, only 6% of the total land is under crop farming, mostly in the riverine areas of the Tana River

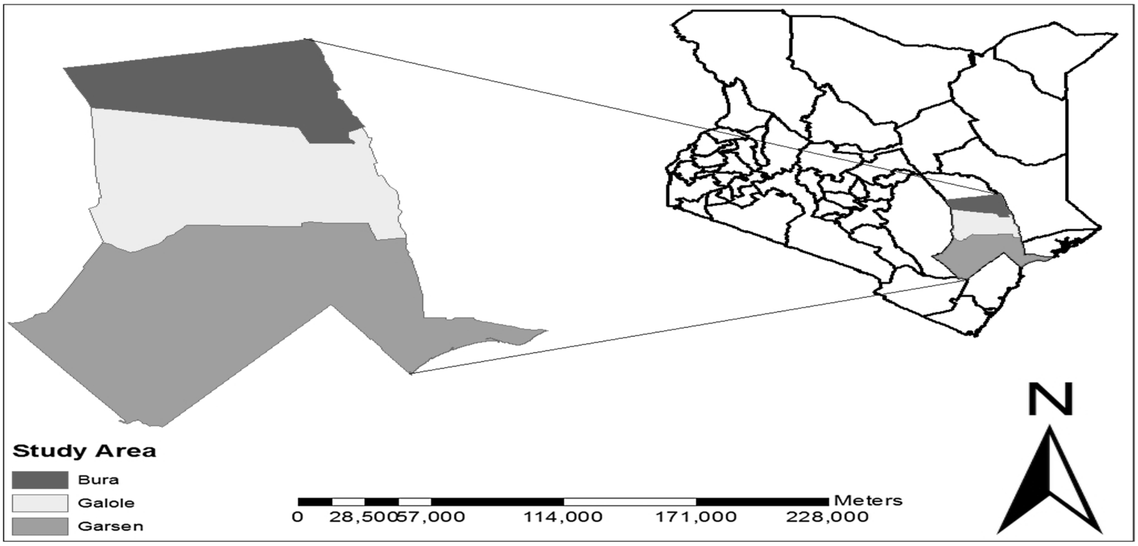

Fig. 1 The study area

County, as the mainland is drier and mostly dedicated to extensive livestock production.

Sampling design and data collection

A multi-stage sampling procedure was used in the selection of a representative sample population. All the three sub-counties that make up Tana River County namely; Bura, Galole and Garsen inhabited by the agro-pastoralists were purposively selected in the first stage of sampling. The second stage involved a systematic random sampling to select five locations from each sub-county. At the third stage, sampling narrowed down to two smaller administrative units (sub-locations) within each location. Simple random sampling technique was used to select ten respondents from each sub-location for the study to give a total of 300 respondents. A semi-structured questionnaire was used to collect data on the adoption of water harvesting structures among the 300 agro-pastoral households in the selected sub-locations. Prior to actual data collection, the questionnaire was pre-tested among 50 households through face to face interviews and reviewed by multi-disciplinary experts to ensure its adequacy and suitability to capture required information. A total of 12 focus group discussions, each comprising of between 10–12 persons, were conducted, four in each sub county. In addition, 24 key informants comprising of individuals from government line ministries, Non-governmental organizations and civil society organizations involved in the natural resource management and livelihoods of communities from the county were interviewed.

Data analysis

The collected data was subjected to descriptive analysis to generate frequencies and cross-tabulations that displayed relationships in the data. The *t-test* and *chi-square* statistic were used to test for significance in differences in the socio-economic characteristics of the adopters and non-adopters of water harvesting structures in the study area. *Chi-square* test was used for nominal data with categorical variables while *t-test* was used to test the differences in means of the continuous variables. A binary choice model was used to determine the factors that influenced adoption of water harvesting structures among the agro-pastoral households. The decision to adopt or not adopt a particular water harvesting structure is a binary decision that can be analyzed using binary choice models. Dichotomous outcomes such as adoption or non-adoption are related to a set of explanatory socio-economic variables that are hypothesized to influence the outcome (Neupane et al. 2002) and can be estimated using probit, logit and linear probability. In this study, a logistic regression procedure using maximum likelihood estimation (Kmenta et al. 1986) was used to estimate the probability of a water harvesting structure being adopted. The Statistical Package for Social Sciences (SPSS version 26) software was used in the estimation of the model (Norusis 2008). A multivariate binary logit model was used because of the consistency of parameter estimation associated with the assumption that error term in the equation has a logistic distribution (Ravallion 2001).

The probability of adopting the water harvesting systems at different level of the independent variable was estimated as:

$$P_i = E(Y = 1/X_i) = \frac{1}{1 + e^{-(\beta_1 + \beta_2 X_i)}} \quad (1)$$

where Y = 1 means the respondent adopted the water harvesting systems, while X_i is a vector of explanatory variables, and *e* is the base of natural logarithm.

Equation 1 can be re-written as

$$P_i = \frac{1}{1 + e^{-z_i}} \quad (2)$$

where $Z_i = \beta_1 + \beta_2 X_i$.

Equation (2) represents a cumulative logistic distribution function. The P_i, given in Eq. (2) gives the probability that the respondents adopted the systems while $(1 - P_i)$, is the probability that all the households adopted the systems.

$$1 - P_i = \frac{1}{1 + e^{zi}} \quad (3)$$

Equation (3) can be simplified as:

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{Z_i}}{1 + e^{-Z_i}} = e^{Z_i} \quad (4)$$

$\frac{P_i}{1-P_i}$ = is the odds ratio that the households adopted the water harvesting systems. Hence the natural log of Eq. (4) can be expressed as shown in Eq. 5:

$$L_i = l_n\left(\frac{P_i}{1 - P_i}\right) = Z_i = \beta_1 + \beta_2 X_i \quad (5)$$

where L represents the log of odds ratios which is in linear form in *X* as well as in the parameters, therefore, the logit equation can be specified as in Eq. 6.

$$L_i = \left(\frac{P_i}{1 - P_i}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon_i \quad (6)$$

where: *X* = *is* a vector of socio-economic factors influencing households' ability to adopt, β = is a vector of coefficient to be estimated, ε = is the error term assumed to be normally distributed with a mean of zero and variance δ^2.

The adoption variable is dependent on other variables of the respondent such as age, gender, level of education and income, source of livelihood, and extension information. The level of significance of each variable was tested using the null hypothesis that these explanatory variables have no effect on the decision to adopt water harvesting structures.

In order to determine whether the explanatory variables were highly linearly related, the presence of multicollinearity and heteroskedasticity in the independent variables was tested. For multicollinearity, a linear correlation coefficient which measures the direction of a linear relationship between two variables was used (Maddala 2001). To quantify the severity of multicollinearity, the Variance Inflation Factor (VIF) was used to measure how much the variance of the estimated regression coefficient increased because of collinearity as shown in Eq. 7. According to Greene, (2002) if VIF (βi) > 5, then multicollinearity is high.

$$VIF = \frac{1}{1 - Ri^2} \quad (7)$$

Explanatory variables and their expected influence on the dependent variable

Several factors were hypothesized to influence the adoption of water harvesting structures in the study area. The factors were generally categorized into socioeconomic and institutional factors. The socioeconomic factors included age, gender, education, household size, herd size and income, while the hypothesized institutional factors were membership in community groups, access to extension services and land tenure (Table 1).

Age

According to the theory of human capital, young heads of a household have a greater chance of being taught new knowledge (Sidibe 2005) and, hence, are better prepared for the adoption of technological innovations (Akroush 2017). Since labor and credit markets are imperfect, older household heads lacking the labor necessary for construction and frequent maintenance of conservation structures may not easily adopt the water harvesting structures (Zegeye et al. 2001). Young people may also be more receptive to new ideas and are less risk averse than the older people (Barret et al. 2004). In this study, we expected age of the household head to have both positive and negative effect on the adoption of water harvesting structures.

Gender

Gender represents differences in adoption orientation between male and female heads of households. Gender determines access to resources and assets particularly in pastoral context (Omollo 2010). Male headed households have more access to productive resources such as land and livestock compared to female counterparts who are constrained by low access to natural resources (Wasonga 2009). Male headed households were therefore expected to adopt the water harvesting structures more than their female counterparts.

Education

Household head's formal education has a positive effect on adoption of water harvesting structures because it

Table 1 Explanatory variables used in the binary logistic model

Variable	Description	Type of measure	Expected sign
Dependent variable			
Adoption	Whether a HH adopted or not	Dummy (1 if yes, 0 if No)	
Explanatory variables			
Age	Age of the HH head	Years (1, 2, 3……n)	−
Gender	Gender of the HH head	Dummy (1 if male, 0 if Female	±
Education	Education level of HH head	0 = None, 1 = Primary, 2 = Secondary, 3 = College	
Monthly Income	Total monthly HH income	1 = < 10,000, 2 = 10,000–20,000, 3 = 20,000–30,000, 4 = > 30,000	+
Land tenure	Type of land ownership	1 = Private, 2 = Community, 3 = Public	±
Membership in a group	Registered member in a farmers group	Dummy (1 if yes, 0 if No)	+
Extension services	Extension information and training	Dummy (1 if yes, 0 if No)	+
Active labour	Readily available labour force	Dummy (1 if yes, 0 if No)	+
Credit	Access to agricultural credit	Dummy (1if yes, 0 if No)	+

enhances management skills and ability to utilize information (Ahmed et al. 2013). Education would expose one to technical skills and knowledge and therefore creates awareness and enhances adoption of water harvesting systems (Hatibu et al. 2003). Education was therefore posited to increase the adoption rate of water harvesting technologies and was measured as the level of basic education attained by the household head.

Household size
The number of family members was hypothesized to either have a positive or a negative influence on adoption of water harvesting structures. A larger household may have cheap and adequate labor for construction and management of water harvesting structures as opposed to a smaller household with no cheap labor (Alene et al. 2008). Consumption needs for a larger family may also be high hence requiring more resources for the household to meet their family needs hence reducing disposable income available for construction of water harvesting structures (Ahmed et al. 2013).

Source of livelihood
Source of livelihood was expected to have a positive influence on the adoption of water harvesting structures. This was measured as the main types of economic activities pursued by households. Households that rely mainly on livestock and crop production are more likely to adopt the water harvesting structures due to their environmental benefits of water conservation for livestock and crops (Manyeki et al. 2013), as compared to those who have alternative sources of livelihood.

Herd size
The size of a household herd was expected to have a positive influence on the adoption of water harvesting structures. In pastoral communities, a large herd size is associated with more wealth (Omollo et al. 2018). Livestock is a productive asset that generates future income to the households through milk production and calving, and are easily sold for cash (Muthee 2006), which means such households can easily afford to construct water harvesting structures. Herd size was measured by the number of tropical livestock units (TLU) of a household.

Household income
Household income was determined by the amount of revenue earned by household on monthly basis in Kenyan Shillings. The level of household income was hypothesized to have a positive influence on adoption of water harvesting structures. A household with high income is expected to have enough capital to venture into more capital-intensive activities such as water harvesting structures (Zegeye et al. 2001).

Extension information
In this study, extension information referred to accessing production and market information and training. Extension services provide the requisite technical assistance and skills required for the construction and management of the water harvesting structures (Khalid et al. 2017). This increases farmers' knowledge and perception of the merits of water harvesting structures through better access to technical information and training provided by the extension personnel (Akroush et al. 2017). Access

to extension information was therefore hypothesized to have a positive influence on the adoption of water harvesting structures among households.

Land tenure

Land tenure was measured as the type of respondents' land ownership and was hypothesized to have both positive and negative influences on the adoption of water harvesting structures by households. On one hand, lack of tenure would make people reluctant to invest in water harvesting structures on land which they do not formally own. Where land ownership and rights of use are complex, it may be difficult to persuade one to improve land that someone else may use later (Ahmed et al. 2013). This implies that households with private ownership are more likely to adopt the water harvesting structures than those under communal ownership. On the other hand, communal ownership of land would mean the community can pool their resources in terms of manpower to construct the water harvesting structures with ease, therefore implying that adoption of water structures is more likely under communal land tenure than in the case of private ownership.

Membership in social groups

According to McKague et al. (2009), community social groups improve cooperation among the pastoralists which enables them to pool their resources together and make proper decisions in the conservation of natural resources hence increasing their adoption of a new technology (Omollo et al. 2018). Social groups provide social capital, and helps farmers to pool resources for collective action, as well as increasing the capacity of members to access services such as credits, extension and information hence making them more likely to adopt the water harvesting structures. Membership in social group was therefore expected to have a positive influence on the adoption of water harvesting structures.

Perception on water harvesting structures

According to Scott et al. (2008), the decision to adopt a new idea, behavior, or product is an active and dynamic process with interactions between the individual, situational factors and contextual factors as well as attributes of the innovation itself. The key to adoption is that the person must perceive the idea, behavior, or product as new or innovative. Rogers' Diffusion of Innovation Theory 1962 seeks to explain how new ideas are adopted, and this theory proposes that there are five attributes of a new idea or approach that effect adoption: relative advantage, compatibility, complexity, trial ability, and observability (Rogers 2003). An even point Likert scale (Akroush et al. 2017) was used to assess the above-mentioned characteristics of adopters and gauge their attitudes by asking the extent to which they agree or disagree with the awareness of the need for water harvesting structures, decision to adopt or reject their initial and continued use.

Results and discussion

Socio-economic characteristics of respondents

Tables 2 and 3 show the socioeconomic characteristics of the sampled households. The results show that those who adopted the water harvesting structures (N = 204) were associated with a significantly ($t_{(300)} = 3.7$, $p = 0.00$) larger herd size (Mean TLU 28.9 ± 16) compared to non-adopters (N = 96) who had a smaller herd size (Mean TLU = 21.9 ± 12.9). Non-adopters were slightly older (Mean = 44.7 years) than the adopters (Mean = 42.6 years). However, the mean age difference between the adopters and non-adopters was statistically insignificant ($t_{(300)} = -1.36$, $p = 0.17$). Those who adopted had a significantly ($t_{(300)} = 3.6$, $p = 0.03$) larger average size of the households than the non-adopters (Table 2). Majority (82.3%) of those who adopted the water harvesting structures were male headed households, while more than half (55.9%) of non-adopters were female headed households. Gender was statistically significant ($\chi^2 = 19.8$, df = 1, $p < 0.000$) indicating that male headed households were more likely to adopt the water harvesting structures compared to their female counterparts (Table 3).

The adopters (86.5%) who were members of community groups were significantly higher ($\chi^2 = 106.9$, $df = 1$, $p = 0.000$) than the non-adopters (23%). There was no significant difference in the education levels of the adopters and the non-adopters ($\chi^2 = 1.09$, df = 3, $p = 0.78$) with 65.6% and 68.1% of adopters and non-adopters having had basic primary education respectively. The results also show that majority (76%) of the adopters had significantly more ($\chi^2 = 96.2$, df = 1, $p = 0.000$) access to extension services compared to non-adopters (17.6%). The main source of livelihood for majority (84.4%) of the adopters was mixed livestock and crop production compared to most of the

Table 2 Socio demographic characteristics of the sampled respondents

Characteristic	Adopters		Non-adopters	
	Mean	Mean	t-ratio	sig
Age (years)	42.6 ± 14.5	44.7 ± 11.8	−1.36	0.17
Household size (number family members)	7.2 ± 1.8	6.4 ± 1.8	3.6**	0.03
Herd size (TLU)	28.9 ± 16	21.9 ± 12.9	3.7***	0.00

***; Significant at 1% level; **: Significant at 5% level; *: Significant at 10% level.

Table 3 Characteristics of respondents

Characteristics	Category	Adopters		Non-adopters		χ^2	Sig
		Frequency (N = 96)	Proportion (%)	Frequency (N = 204)	Proportion (%)		
Gender of HH head	Male	79	82.3	90	44.1	19.8***	0.00
	Female	17	17.7	114	55.9		
Education	None	33	34.4	65	31.9	1.088	0.78
	Primary	52	54.2	108	52.9		
	Secondary	10	10.4	26	12.7		
	College	1	1	5	2.5		
Main source of livelihood	Employment	0	0	7	3.4	146.9***	0.00
	Cattle keeping	12	12.5	123	60.3		
	Farming	3	3.1	25	12.3		
	Business	0	0	23	11.3		
	Livestock and crop production	81	84.4	26	12.7		
Monthly income (Ksh)	< 10,000	46	22.5	82	85.4	105.8***	0.00
	10,000–20,000	116	56.9	12	12.5		
	20,000–30,000	37	18.1	2	2.1		
	> 30,000	5	2.5	0			
Land tenure	Private	60	62.5	39	19.1	155.94***	0.00
	Community	36	37.5	165	80.9		
Farmer groups	Member	83	86.5	47	23	106.9***	0.00
	Non-member	13	13.5	157	77		
Extension	Accessed	73	76	36	17.6	96.2***	0.00
	Not accessed	23	24	168	82.4		
Access to credit	Yes	78	81.2	12	5.9	48.6	0.00
	No	18	18.8	192	94.1		
Active labour	Available	84	87.5	40	19.6	124.1***	0.00
	Not available	12	12.5	164	80.4		

***; Significant at 1% level; **: Significant at 5% level; *: Significant at 10% level

Source: Household interviews (N = 300)

non-adopters (60.3%) whose main source of livelihood was cattle keeping. The percentage of adopters (62.5%) who privately owned land was significantly higher ($\chi^2 = 155.94$, df = 1, p = 0.000) than that of non-adopters (19.1%) showing that land tenure is likely to influence the adoption of water harvesting structures. Significantly (p = 0.000), more adopters (81.2%) had access to credit and active labor (87.5%) compared to non-adopters. Monthly household income levels were significantly different ($\chi^2 = 105.8$, df = 4, p = 0.000) between the adopters and the non-adopters, with majority (77.5%) of the adopters making at least more than Ksh. 10,000 a month compared to non-adopters (14.6%). These results show that income, extension information, land tenure, availability of active labor, membership in farmer groups, access to credit, gender of household head, herd size and household size are likely determinants of the adoption of water harvesting structures in agro-pastoral areas.

Perception of respondents on water harvesting structures

The results in Table 4 show that majority of the adopters (81.2%) believe that water harvesting structures have relative advantage in reducing agricultural risks by enhancing productivity and efficiency in conserving water compared to non-adopters (25.5%). The adopters (77.1% who believed that the water structures are compatible with their needs was not significantly higher ($\chi^2 = 0.7$, df = 1, p = 0.481) than non-adopters (72.5%). This means that in terms of the compatibility of water harvesting structures, all the adopters and non-adopters believe that the water harvesting structures are consistent with their needs, and experiences hence they are essential. For water harvesting structures such as water pans and Zai pits, it entails directing runoff from some external catchment area to where it is desired. In ASALs areas where soils often cannot absorb the heavy downpours, ground catchment rain water harvesting acts as a tool to increase infiltration and decrease runoff. This thus helps to improve yield during a

Table 4 Perceptions of the respondents on water harvesting structures

Attributes of water harvesting structures	Percentage of Adopters		Percentage of Non-adopters		χ^2	Sig
	Agree	Disagree	Agree	Disagree		
Relative advantage in reducing agricultural risks	81.2	18.8	25.5	74.5	82.66***	0.00
Compatible with existing needs and socially acceptable	77.1	22.9	72.5	27.5	0.70	0.481
Complex and difficult to understand and use	12.5	87.5	83.3	16.7	− 0.68***	0.00
Triable and easy to follow and implement	55.2	44.8	53.9	46.1	0.044	0.901
Observable benefits	80.2	19.8	78.9	21.1	0.066	0.88

***; Significant at 1% level; **: Significant at 5% level; *: Significant at 10% level

normal year, and more importantly, helps to prevent crop failure when rains are below the seasonal average.

Regarding the complexity and difficulty in constructing water harvesting structures in their farms, most of non-adopters (83.3%) significantly believed ($\chi^2 = -0.68$, df = 1, p = 0.00) that it is quite difficult to construct the structures and therefore they needed more technical skills and knowledge compared to only 12.5% of the adopters. All the adopters and the non-adopters agreed that water harvesting structures can be tried in demonstration plots before being implemented ($\chi^2 = -0.044$, df = 1, p = 0.901). Demonstration farms are the most effective extension education tools for demonstrating technical skills including proper citing of the catchment areas, formulation of technical designs, and building of the structures (Moser and Barrett 2006). For pastoralists, demo plots provide an opportunity to demonstrate and teach appropriate water harvesting technologies, as well as venues to test new methods side by side with traditional methods. Although they require considerable time and effort, the payback comes when farmers more readily adapt practices, they perceive to be effective and appropriate under local conditions (Scott et al. 2008). Majority of the respondents (79.3%) agreed that water harvesting structures have observable environmental benefits even though there was no significant difference ($\chi^2 = -0.066$, df = 1, p = 0.088) between the adopters (80.2%) and non-adopters (78.9%).

Factors that determine adoption of water structures by households

Table 5 shows that the mean VIF for exploratory variables included in the model was 1.33, which is lower than 5 hence no multicollinearity was detected. All the independent variables used were therefore uncorrelated and independent making it appropriate for the model to estimate the relationship between each independent variable and the dependent variable independently.

Table 5 Multicollinearity test for the explanatory variables

Model variables	Tolerance	VIF
Gender of respondent	0.810	1.23
Age of respondent	0.782	1.27
Education level	0.945	1.05
Main source of livelihood	0.573	1.74
Average monthly HH income	0.571	1.75
Member of farmers' group	0.682	1.46
Extension services	0.664	1.51
Land tenure	0.804	1.24
Access to credit	0.759	1.32
Availability of active labor	0.754	1.32
Mean VIF		1.33

Table 6 Parameter estimates of Binary Logit model

Variable	β	S. E	Wald	Exp (β)	*P value*
Gender	− 1.102	0.748	2.171	0.332	0.141
Age	− 0.011	0.025	0.181	0.989	0.671
Education	− 0.037	0.514	0.005	0.963	0.942
Main source of livelihood	0.659	0.241	7.504	1.934**	0.006
Monthly income	2.410	0.630	14.645	0.090***	0.000
Land tenure	− 2.220	1.099	4.081	0.109*	0.043
Extension information	2.159	0.726	8.842	0.115**	0.003
Access to credit	− 0.556	1.222	0.207	0.574	0.649
Active farm labour	3.623	0.827	19.189	0.027***	0.000
Member of farmer group	3.711	0.871	18.157	0.024***	0.000
Constant	21.149	4.222	25.094		

Statistical significance level: ***1%, **5%, *10%; Chi-square (df = 10) = 296.49 ($p < 0.000$); − 2log likelihood = 79.63; Cox and Snell $R^2 = 0.628$; Nagelkerke $R^2 = 0.879$

The results show that the model is statistically significant (p = 0.00) and the independent variable explains 87.9% ($R^2 = 0.879$) of the variation in households' decision to adopt the water harvesting structures in the study area (Table 6). Out of the ten variables tested in the model, access to extension services and training, monthly income, main source of livelihood, land tenure, membership in community groups and availability of active labor were found to significantly influence the adoption of water harvesting structures by households.

The results imply that households with better economic standing, measured by the total value of their monthly income are more likely to adopt the labor-intensive technologies such as water harvesting structures. This is because such households are expected to have more disposable income, and are therefore able to afford hired labor required for construction and management of water harvesting structures. As reported by Manyeki et al. (2013), labor cost for construction and maintenance of water harvesting structures is one of the most important factors that determine adoption of such technologies at farm level. The results show that many farmers in the study area were low income earners. This means that they may not afford the manpower to move large amounts of earth that is necessary in some of the large water harvesting systems such as water pans (Rosegrant and Cai 2002). Akudugu et al. (2012) reported that modern agricultural production technologies that were capital intensive were less likely to be adopted. This explains the positive and significant influence of monthly income on the adoption of water harvesting structures. Adoption propensity of most technologies increases with the percentage increase in disposable income because relatively rich households are able to afford labor and the inputs required for the technologies, and are less risk averse, perhaps reflecting economies of scale (Tigabu and Gebeyehu 2018).

Although most households in pastoral communities rely on family labor, exchange and hired labor is relatively used more in labor intensive technologies (Lugusa 2015). This means that households with access to exchange or hired labor will be in a better position to adopt water harvesting structures. According to Bardasi et al. (2011), the adoption of labor-intensive technologies might also put a greater burden on family labor, as their time might be reallocated from other household's income generating activities. Therefore, households without access to family labor or constrained by imperfections in credit and labor markets might face difficulties in hiring (Vandercasteelen et al. 2018) or reallocating family labor away from wage employment to additional farm activities (Barrett et al. 2004). As construction of water harvesting structures is very labor intensive, adoption might be difficult for labor-constrained households which are unable to invest more person-hours of labor in water harvesting structures. This explains why the results show that availability of labor has a positive and significant effect on the adoption of water harvesting structures.

Adoption of water harvesting structures require technical skills including proper citing of the catchment areas, formulation of technical designs, and building of the structures. Therefore, for effective implementation and subsequent adoption of water harvesting technologies, farmers would require technical know-how and skills (Khalid et al. 2017). In addition, farmers may need to be mobilized and trained on the use of water harvesting technologies and sensitized on the potential socioeconomic benefits of adopting them (Adesina and Chianu 2002), underscoring the role of extension services. The results show that access to extension services has a positive and significant effect on the adoption of water harvesting structures. Extension officers are able to contextualize new ideas and innovations to suit local realities (Ahmed et al. 2013). It is tempting to assume that a system which works in one area will also work in another, superficially similar, zone. However, there may be technical dissimilarities such as intensity of rainfall and distinct socio-economic differences hence the need for extension officers who understand the local area to contextualize technologies for easier adoption. Extension services in the study area are provided by the county government and development agencies who however last in an area only for the short duration of the project. This leaves the county government with the sole mandate of providing long term extension services. In addition, farmers are reluctant to adopt new technologies due to socio-cultural factors such as reluctance to diversify into crop production by the pastoral community, and lack of evidence of impact of these technologies on production and incomes through demonstration plots. Extension involves field visits, and workshops on aspects related to water conservation and other relevant value chains. These include crop planting and growing times, input utilization and value addition, and amount of product to sell on the market as well as fodder establishment and conservation (Kidake et al. 2016). Improved participation, mobilization and training of the local people would create an understanding of water harvesting technologies and make room for more adoption.

There was significant influence of land tenure on adoption of water structures. The descriptive statistics show that majority of pastoralists who adopted the water harvesting structures privately owned land. This is partly explained by the fact that households may be reluctant to invest in water harvesting structures on land which they do not individually own such as a communal land. Where land ownership and rights of use are complex, it may be difficult to persuade one to improve land that someone else may use later. To the contrary, Akroush et al. (2017) found that in Jordanian arid lands, the adoption decreased when land was privately owned, and given the fact that the upfront cost of water harvesting technologies was too big and thus farmers were more interested to invest as a group or on communal lands in order to share the cost of adoption.

Membership in community groups significantly increased the adoption of water harvesting structures. Community groups play a significant role in rural development, particularly in arid and semi-arid areas by building on the knowledge that underlies socio-cultural practices when going for new development opportunities. Arasio et al. (2020), while studying the group dynamics in pastoral areas affirmed that groups are open to adopt external knowledge when it helps them to improve their practices. Community groups also improve cooperation among the pastoralists which enables them to pull their resources together and make collective decisions in the conservation of natural resources (Njuki, et al. 2008; McKague et al. 2009). This could explain why membership in community social groups was found to be positive and significant in influencing adoption of water structures. According to Van Rijn et al. (2012), social capital plays an important role in technology diffusion and adoption because local people are more likely to be motivated to participate with genuine commitment in initiatives that lead to sustainable changes in agriculture and resource management. The positive correlations therefore imply that adoption of water harvesting structures increase with increase in the levels of group involvement. This result corroborates the findings of Matata et al. (2010) who in their study on socio-economic factors influencing adoption of improved fallow practices among small scale farmers in Tanzania, found that membership in farmer groups positively influenced adoption of improved fallows.

Conclusion

This study reveals that both household socio-demographic, economic and institutional characteristics should be considered in the dissemination of and widespread adoption of water harvesting structures at household level. The technical aspects of rainwater harvesting systems have been stressed in pastoral areas, though these results show that it takes more than just the engineering aspects. The results demonstrate that the adoption process of water harvesting structures has a social element, and collegial interactions. Pastoralists require technical know-how and skills, capital, and organizational support for the successful adoption and use of water harvesting systems. Social and cultural aspects prevailing in an area of concern are therefore paramount and will affect the success or failure of the promoted techniques. Enhancing our understanding of these factors could provide valuable information to guide dissemination efforts and thereby increase the efficiency of implemented innovations.

We therefore recommend the need to design and develop alternative effective policy instruments and mechanisms, strong institutional options for extension services, technical assistance, training and capacity building that will facilitate adoption of water harvesting structures through participatory practices to ensure better fit to the needs of agro-pastoralists. Creation of strong networking among different institutions related to applying water harvesting structures and involvement of civil societies, public and private financial institutions and support services could be an example of mechanisms to enhance the adoption of water harvesting structures in pastoral areas of Kenya.

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Authors' contributions

AIL contributed to the conception and design of the study, collected the data, carried out analysis and interpretation of data, drafted the manuscript and submitted the approved version. OVW contributed to the conception and design of the study, assisted in the interpretation of the data, revised the manuscript for intellectual content and gave approval of the version to be published. LWR contributed to the conception of the study, facilitated the acquisition of funds for the study, coordinated the data collection process, revised the manuscript critically for intellectual content and gave approval of the version to be published. MMN contributed to the conception and design of the study, guided the data analysis process, revised the manuscript for intellectual content and gave approval of the version to be published. FKS contributed to the conception of the study, revised the manuscript for intellectual content and gave approval of the version to be published. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated and analyzed during this study are included in this published article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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