Adoption of on-farm water management strategies and its impact on household welfare: Evidence from the Upper Ewaso Ng'iro North Catchment Area, Kenya

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Abstract

On-farm water management strategies can be classified into technological and non-technological options. While, numerous studies have assessed the drivers of the adoption of conservation strategies, few have assessed the welfare impacts of adoption. Analysis was conducted on cross-sectional farm household data collected from 652 households randomly selected from eight sub-catchments of the Upper Ewaso Ng'iro North Catchment Area (ENNCA). The study assessed the determinants of adoption of on-farm water management strategies and estimated the impact of adoption on household consumption per adult equivalent, using the Multinomial Endogenous Switching Regression (MESR) framework. The results show that adoption of on-farm water management strategies, is influenced by household socioeconomic and institutional factors; and adoption of all WMS offers the greatest impact on household welfare. Therefore, households need to be trained on the importance of the adoption of multiple water management strategies so as to benefit from substitutionality and complementarity of these technologies.

Key words

Adoption; Multinomial Endogenous Switching Regression; Water Management; Upper Ewaso Ng'iro; Impact; Welfare; Household Consumption per Adult Equivalent,

Introduction

Depletion of water resources is emerging as a threat to the sustainable growth of agriculture in many parts of Sub-Saharan Africa (SSA) and particularly in Kenya. Conservation of water catchment areas has recently received special attention due to the increasing water stress globally and more specifically in SSA, not to mention the challenges posed by climate change. Sustainable water management has become more imperative in consideration of the circumstances facing smallholder farmers, since, sustainable water management is associated with improved household food security, nutrition, livelihoods and welfare (1-7).

On-farm water management strategies can be classified into technological and non-technological options. Technologies include methods of enhancing rainwater capture and use, on-farm storage, and improved land and crop management practices such as use of improved crop varieties, green houses, drip irrigation, solar irrigation, pumping and use of low quality water (water recycling/ re-use). Non-technological solutions include social and institutional innovations; expanding the area in production to optimize the use of rainfall; increasing water use efficiency and crop productivity; on-farm water management to minimize water losses by evaporation; use of improved cropping systems and agronomics, such as conservation tillage and climate smart agriculture; development of financial frameworks to provide incentives for the adoption of best practices; evaluation of rainfall patterns to determine quantity and quality available for agriculture use and crop scheduling (8-10).

While, numerous studies have assessed the drivers of the adoption of SWC, few have proceeded to assess the welfare impacts due to the related estimation and modelling challenges associated with adoption of multiple technologies (11-16). The current study adopted the approach by 11 and 13, since, farmers adopted different combinations of WMS in a bundle, which are all mutually exclusive, and as such farmers were assumed to adopt the WMS mix that maximized their household welfare, under their production constraints following household utility theory.

Materials and methods

The study was undertaken in the Upper Ewaso Ng’iro North Catchment Area (ENNCA), which is the catchment area for the Ewaso N’giro River basin. The Ewaso N’giro River basin is the largest basin in Kenya (Ewaso Ng’iro North River Basin Development Authority (17). According to Mungai et al. (2004) the Upper Ewaso Ng’iro North Basin is located to the north and west of Mount Kenya, extending to the Aberdare Ranges between longitudes $36^{0}30'$E and $37^{0}45'$E and latitudes $0^{0}15'$N and $1^{0}00'$N. The upper catchment area is highly utilized for agricultural production due to favorable weather conditions, fertile soils and irrigation water availability through river abstractions. The main economic activity in Upper Ewaso Ng’iro North Catchment, is small-scale farming (rain-fed and irrigation), small-scale fishery and pastoralism. The area ranges from high potential high altitude to low potential arid and semi-arid zones. Due to the arid nature of most parts of the basin, the atmospheric demand for water is very high (18-19).

Data was collected in the period between September, 2019 and December, 2019 from a sample of 652 households. Multistage sampling technique was employed in the study. In the first stage, eight sub-catchments were sampled randomly out of the twenty one sub-catchments of the Upper ENNCA; as a result the following sub-catchments were sampled; Ewaso Narok, Pesi, Rongai, Naromoru, Likii, Timau, Sirimon and Ngare Ndare. It is important to note that the eight sampled sub-catchments are also the WRUAs, since WRUAs are named as per sub-catchment. In the second stage stratified sampling was done disproportionately to population size of these eight sub-catchments, since the number of households in each sub-catchment was unknown. Finally, simple random sampling was undertaken using a list from the WRUAs.

The study utilized both primary and secondary data sources. Primary data was collected from households, WRUAs and key informants. Secondary data was collected from sources such as books, journals and reports. Data collected for the study included household data, group data, farm produce data and income data. A semi structured questionnaire was administered to the small-scale farmers by trained enumerators, using the World Bank's Computer Aided Personal Interview (CAPI) Program, through face to face interviews. The map of the sub-catchment areas is shown in Fig 1:

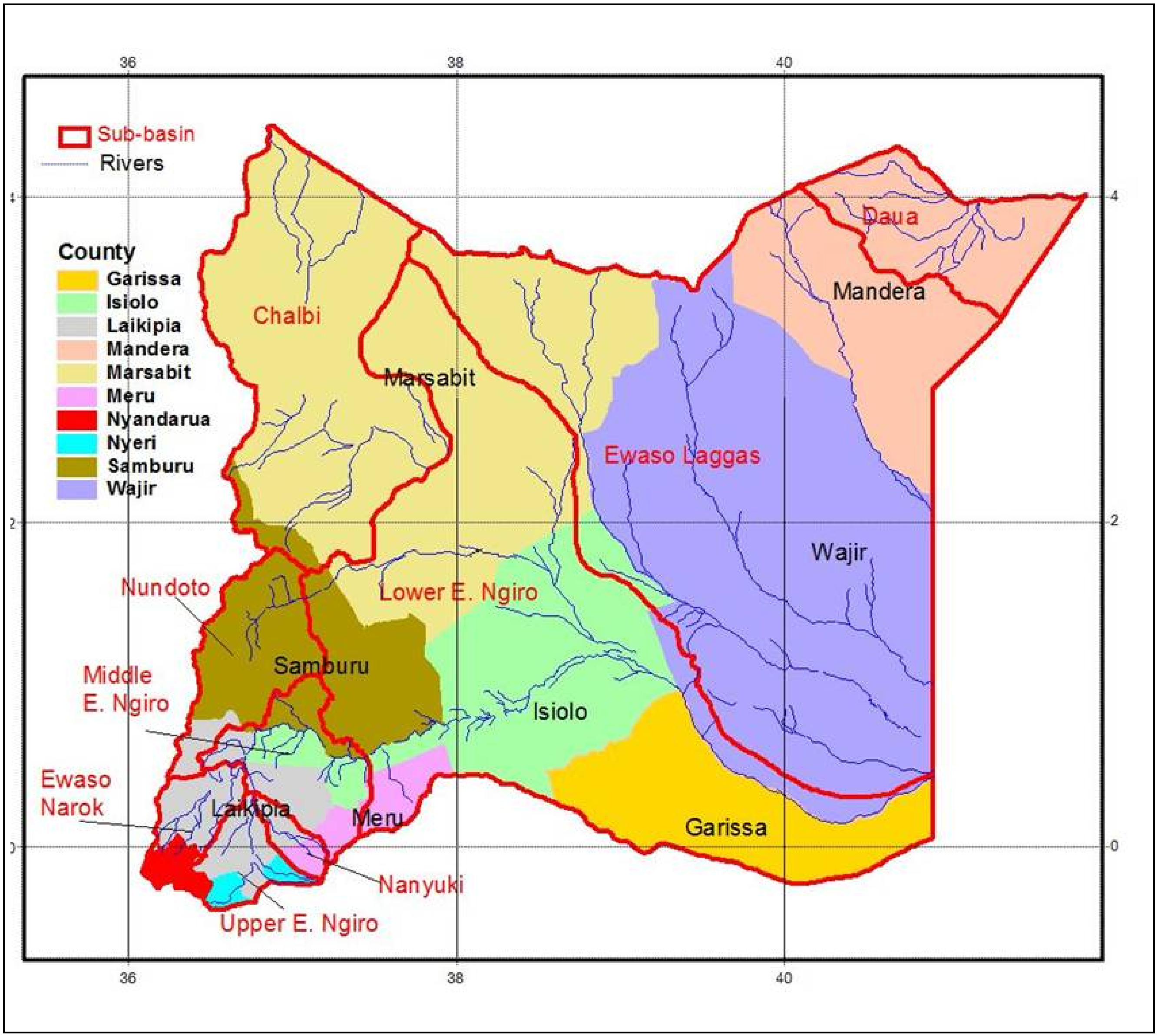

Fig 1: Map showing Upper Ewaso Ng'iro Sub-catchments

Source: (17)

Analytical Framework

Determination of the adoption and the effect of adoption of on-farm water management strategies on household consumption expenditure per adult equivalent.

The first aim of the study was to determine the factors that influenced the adoption of different WMSs combinations. The second aim was to determine the impact of the adoption of different WMSs combinations on household welfare measured by household consumption expenditure per adult equivalent. Further, the adoption decision may be affected by unobserved heterogeneity and self-selection bias which needed to be addressed. Therefore, the most preferred model to achieve both aims would be the Multinomial Endogenous Switching Regression (MESR) following (20).

The MESR framework has the advantage of evaluating alternative combinations as well as individual practices. It also captures self-selection bias as well as the interactions between choices of alternative practices (21-22). MESR assesses the effect of adoption in two stages. In the first stage, household choice of WMS combinations was modelled using a multinomial logit selection model, while recognizing the interrelationship among WMS choices. In the second stage, the impacts of each WMS combination on the outcome variable (in this case household consumption expenditure per adult equivalent) were evaluated using the ordinary least squares (OLS) with a selectivity correction term from the first stage. For identification, the study used WRUA membership and sources of extension service as instrumental variables. A simple falsification test was carried out to check the validity and the admissibility of the instrumental variables following (23), to confirm that WRUA membership jointly affects the choice of WMS and not the outcome variable for households that did not adopt. The MESR can be specified as follows:

Specification of the multinomial endogenous switching regression (MESR) model

In the first stage modelling, the study assumes that smallholder farmers aim to maximize their net welfare Y_i (household consumption expenditure per adult equivalent) by comparing the positive welfare provided by *m* alternative WMS. The requirement for a farmer *i* to choose a WMS, j, over any alternative, m, is that $Y_{ij} > Y_{im}, and\ m \neq j$, or equivalently $\Delta Y_{im} = Y_{ij} - Y_{im} > 0 \quad and\ m \neq j$. The expected net welfare, Y^*_{ij}, that the farmer derives from the adoption of WMS j, is a latent variable determined by observed characteristics X_i and unobserved characteristics $\in_{ij}$as shown in equation 1.

$$Y^*_{ij} = X_i\beta_j + \in_{ij} \tag{1}$$

Let *I* be an index that denotes the farmer's choice of the WMS, such that:

$$I = \begin{cases} 1\ iff\ Y^*_{iI} > max\ (Y^*_{im})\ or\ \eta_{iI} < 0, & m \neq j \\ \quad \ldots & for\ all\ m \neq j \\ j\ iff\ Y^*_{ij} > max\ (Y^*_{ij})\ or\ \eta_{ij} < 0, & m \neq j \end{cases} \tag{2}$$

Where, $\eta_{ij} = max_{m \neq j}\big((Y^*_{im} - Y^*_{ij}\big) < 0$, (24). Equation 2 implies that the i^{th} farmer will choose WMS *j,* to maximize the expected positive welfare, if WMS *j* provides greater expected positive returns than any other WMS *m≠j,* that is, if, $\eta_{ij} = max_{m \neq j}\big((Y^*_{im} - Y^*_{ij}\big) > 0$. Assuming that the error term ϵ are identically and independently Gumbel distributed, the probability that a farmer *i,* with characteristics, X_i will choose WMS, *j,* can be specified by a multinomial logit model as specified by 25 as shown in equation 3. The maximum likelihood function is used to estimate the parameters of the latent variable model.

$$P_{ij} = \Pr\big(\eta_{ij} < 0 \,\big|\, X_i\big) = \frac{\exp\,(X_i\beta_j)}{\sum_{m=1}^{J} \exp\,(X_i\beta_m)} \tag{3}$$

In the second stage of the MESR, the relationship between the outcome variable (household consumption expenditure per adult equivalent) and a set of exogenous variables Z (farmer, farm household characteristics and institutional factors) is estimated for the chosen WMS combination. In the study, the base category is formed by famers who did not adopt any WMS, and is denoted as *j=1.* In the remaining set of possible WMSs, *j=2,3,4,5,……,16,* whereby at least one WMS is adopted by the farmer. The outcome equation for each possible regime *j* is therefore shown in equation 4:

$$\begin{cases} Regime\ 1: Q_{i1} = Z_I\alpha_1 + \mu_{i1}\ if\ I = 1 \\ Regime\ J: Q_{ij} = Z_j\alpha_j + \mu_{ij}\ if\ j = 1 \end{cases} \tag{4}$$

Where, Q_{ij} is the outcome variable (household consumption expenditure per adult equivalent), for the i^{th} farmer in regime j, and the error terms (μ) are distributed with $E(\mu_{ij} \mid X,Z) = 0$, and $var(\mu_{ij} \mid X,Z) = \sigma_j^2$. Further, Q_{ij} is observed if, and only if WMS is adopted, which occurs when, $Y_{ij}^* > max_{m\neq j}(Y_{im}^*)$. If the error terms ϵ's and μ's are not independent, OLS estimates obtained from equation 4 will be biased. A consistent estimation of $\alpha_j$requires inclusion of the selection bias correction terms obtained in the first stage of the alternative WMS in equation 4. The MESR assumes the following linearity assumption:

$$(U_{ij} \mid \in_{Ii} \ldots\ldots \in_{ij}) = \sigma_j \sum_{m\neq j}^{j} r_j\,(\in_{im} - E(\in_{im})) \tag{5}$$

With $\sum j_m = 1 r_j = 0$ by construction, the correlation between the error terms sums to zero. Using this assumption, the equation of the MESR in equation 3. is specified as shown in equation 6:

$$\begin{cases} Regime\ 1: Q_{i1} = Z_I\alpha_1 + \sigma_i\lambda_i + \omega_{i1}\ if\ I = 1 \\ Regime\ J: Q_{ij} = Z_j\alpha_j + \sigma_j\lambda_j + \omega_{ij}\ if\ I = J \end{cases} \tag{6}$$

Where σ_j is the covariance between the ϵ's and μ's. On the other hand, $\omega's$ are the error terms with an expected value of zero, andλ_j, is the Inverse Mills Ratio, computed from the estimated probabilities in the MNL model in equation 3, computed using the formula in equation 7.

$$\lambda_j = \sum_{m\neq j}^{j} \rho_j \left[\frac{\widehat{P_{im}} \ln(\widehat{P_{im}})}{1-\widehat{P_{im}}} + \ln(\widehat{P_{ij}}) \right] \tag{7}$$

Where σ_j is the covariance between the ϵ's and μ's. In the multinomial choice setting there are J-1 selection bias correction terms, one for each alternative WMS combination. The standard errors in equation 6 are bootstrapped to account for the heteroscedasticity arising from the generated regressor λ_j.

Given, the above framework, the average treatment effects can be computed in a counterfactual framework, following (21, 26, 27) whereby, the ATT in the actual and counterfactual scenarios is computed as follows:

Adopters with adoption (actual adoption in the sample) is shown in equation 8 and 9:

$$\begin{cases} E\big(Q_{i2} \,\big|\, I=2\big) = Z_i\alpha_2 + \sigma_2\lambda_2 & (a) \\ E\big(Q_{ij} \,\big|\, I=J\big) = Z_i\alpha_j + \sigma_j\lambda_j & (b) \end{cases} \tag{8}$$

$$\begin{cases} E\big(Q_{iI} \,\big|\, I=1\big) = Z_i\alpha_I + \sigma_I\lambda_I & (a) \\ E\big(Q_{ij} \,\big|\, I=3\big) = Z_i\alpha_3 + \sigma_3\lambda_3 & (b) \end{cases} \tag{9}$$

From Equation 9, the value of *I* can be taken up to the n^{th} possible WMS combination terms, where for this study $n=12$.

The counterfactual scenario which represents, adopters had they decided not to adopt is shown in equations 10 and 11.

$$\begin{cases} E\big(Q_{iI} \,\big|\, I=2\big) = Z_i\alpha_I + \sigma_I\lambda_2 & (a) \\ E\big(Q_{ij} \,\big|\, I=J\big) = Z_i\alpha_I + \sigma_I\lambda_j & (b) \end{cases} \tag{10}$$

$$\begin{cases} E\big(Q_{i2} \,\big|\, I=1\big) = Z_2\alpha_2 + \sigma_2\lambda_I & (a) \\ E\big(Q_{ij} \,\big|\, I=3\big) = Z_2\alpha_3 + \sigma_3\lambda_3 & (b) \end{cases} \tag{11}$$

The expected values are used to derive unbiased estimates of the ATT. The ATT is defined as the difference between the equations 8(a) and equation 10(a). The ATT can be computed as shown in equation 12.

$$ATT = E\big[Q_{i2} \,\big|\, I=2\big] - \big[Q_{iI} \,\big|\, I=2\big] = Z_i(\alpha_2 - \alpha_1) + \lambda_2(\alpha_2 - \alpha_1) \tag{12}$$

Where the first term on the right side of equation 12 represents the expected change in the mean outcome if adopters attributes had the same welfare with non-adopters of WMS, i.e. if a farmer associated with a particular WMS combination, had the same net welfare as a farmer not associated with any WMS adoption. The second term, with λ_j, is the selection term that captures all potential effects of differences in unobserved variables. Finally the average treatment effect on the untreated (ATU) is the difference between equations 9(a) and 11(a), and can be specified as:

$$ATU = E[Q_{iI} \mid I = 1] - E[Q_{i2} \mid I = 1] = Z_i(\alpha_2 - \alpha_1) + \lambda_2(\alpha_2 - \alpha_1) \qquad (13)$$

Description of WMS combinations

Households adopt a combination of WMS and from the household utility theory and Roger’s theory of technology adoption, adoption of technologies for individual households is influenced by different variables. Therefore, considering individual adoption would be erroneous since adoption may be interdependent on different household circumstances. The study therefore adopted the MESR model to assess the determinants of the different WMS combinations. The anticipation of the study was that, at least a household adopted any one of the seventeen considered WMSs. This would yield 289 possible combinations of the 17 WMS technologies considered, which would not be plausible for analysis. In order, to overcome this challenge, the 17 WMSs were categorized into four categories with respect to their classification, as follows; category one; included rain water harvesting and storage, to include water harvesting and storage WMSs. Category two included; soil based water conservation techniques, which included all WMS that improve soil water retention capacity. Category 3; cropping techniques; which included cropping patterns and crop technologies. And Category 4; included WMS technologies that seek to optimize or economize or minimize on-farm water use. The four combinations would yield 16 combinations which are feasible for economic modelling, at the scale of this study. The four categories were summarized in table 1.

Table 1: WMS categories

Cropping techniques	**Soil water retention techniques**	**Water harvesting and storage**	**Water use optimization techniques**
Improved crops	Conservation tillage	Gutters and Tanks	Drip Irrigation
Crop scheduling	Zero tillage	Water Pans with dam liners	Sprinkler irrigation

	Grass strips	Water pans without dam liners	Water recycling/re-use
	Terracing		greenhouses
	Agroforestry		Drip irrigation
	Manure		
	Mulching		

All the possible combinations from the four categories are shown in table 2, where C, represented cropping WMS, S, represented Soil Water retention WMSs, H, represented rain water harvesting and storage WMSs and O, represented water use optimization WMSs. $C_0S_0H_0O_0$ represents the base outcome/control group of farmers who did not adopt any WMS. $C_1S_1H_1O_1$ represents the extreme end of farmers who adopted all WMSs.

Table 2: All possible WMS combinations

Combination	Description
$C_0S_0H_0O_0$	No adoption (base outcome)
$C_1S_0H_0O_0$	One strategy adopted
$C_0S_1H_0O_0$	
$C_0S_0H_1O_0$	
$C_0S_0H_0O_1$	
$C_1S_1H_0O_0$	Two strategies adopted
$C_1S_1H_0O_0$	
$C_1S_0H_1O_0$	
$C_1S_0H_0O_1$	
$C_0S_1H_1O_0$	
$C_0S_1H_0O_1$	

$C_0S_0H_1O_1$	
$C_1S_1H_1O_0$	Three strategies adopted
$C_1S_1H_0O_1$	
$C_1S_0H_1O_1$	
$C_0S_1H_1O_1$	
$C_1S_1H_1O_1$	Four strategies adopted

Results and Discussions

Descriptive statistics of the different WMSs combination adoption

The results showed that 97.7% of the households adopted at least one water management strategy. Majority of the households adopted roof water tapping, agroforestry, manure application, grass strips, and mulching with an adoption rate of 66.326%, 48.93%, and 37.73%, 13.65% and 12.58% respectively as shown in figure 1. Adoption of water pans with and without dam liners, use of improved crop varieties, conservation tillage, zero tillage, crop scheduling, terracing, drip irrigation, and water recycling/re-use remain low with a range between 1.23% and 10.44%. On the other hand no household adopted green houses or hydroponics technology despite them being advanced technologies. The results show that despite the benefits of WMS adoption rates remain low across the strategies. As such it is important to understand the factors that influence adoption of the individual WMS strategies.

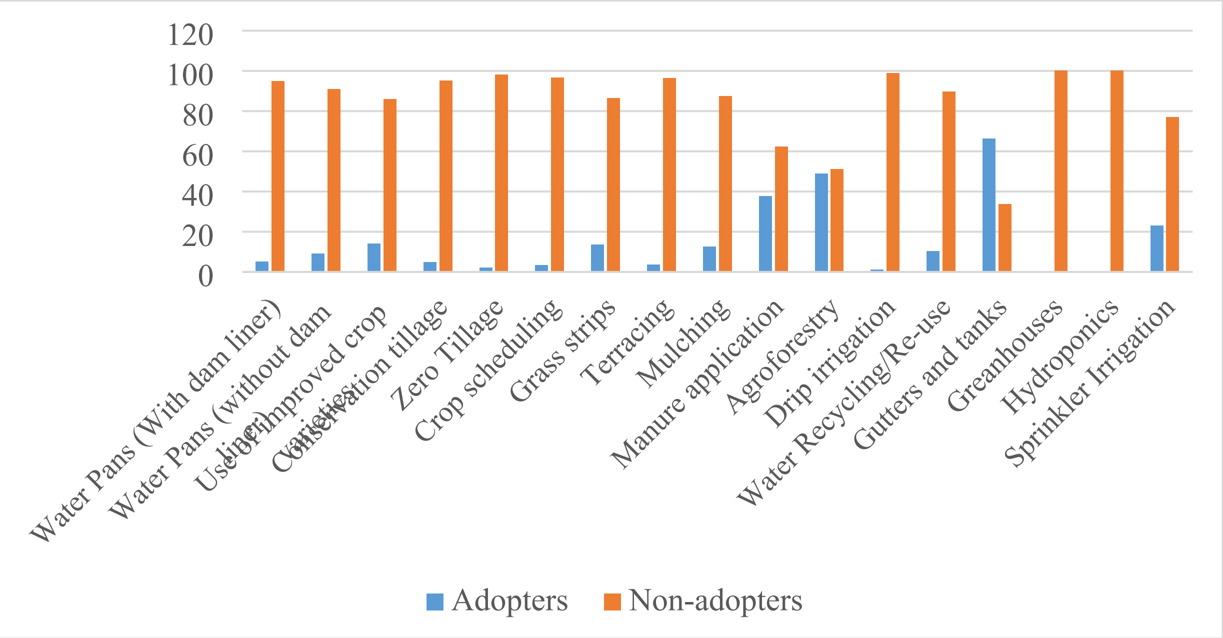

Figure 1: Individual WMS adoption

The results further showed that the most popular WMS combination is the, soil and water harvesting combination ($C_0S_1H_1O_0$), whereby, it was adopted by at least 25 percent of sampled households as shown in table 3. Followed by the, soil, water harvesting and water optimization combination ($C_0S_1H_1O_1$) at 13 percent and soil techniques only ($C_0S_1H_0O_0$) at 12 percent. While, adoption of all the WMSs is assumed to have better outcomes, it is not as popular since it was adopted by only 4 percent of the households.

Table 3: Summary statistics of the adoption of WMS alternatives

Combination	Frequency	Percent	Cum.percent
$C_0S_0H_0O_0$	15	2.30	2.30
$C_1S_0H_0O_0$	12	1.84	4.14
$C_0S_1H_0O_0$	81	12.42	16.56
$C_0S_0H_1O_0$	125	19.17	35.74
$C_0S_0H_0O_1$	0	0	35.74
$C_1S_1H_0O_0$	10	1.53	37.27
$C_1S_0H_1O_0$	8	1.23	38.50
$C_1S_0H_0O_1$	0	0	38.50
$C_0S_1H_1O_0$	162	24.85	63.34

$C_0S_1H_0O_1$	46	7.06	70.40
$C_0S_0H_1O_1$	37	5.67	76.07
$C_1S_1H_1O_0$	32	4.91	80.98
$C_1S_1H_0O_1$	10	1.53	82.52
$C_1S_0H_1O_1$	0	0	82.52
$C_0S_1H_1O_1$	85	13.04	95.55
$C_1S_1H_1O_1$	29	4.45	100.00
Total	**652**	**100**	**-**

Factors influencing adoption of alternative WMS technologies

Table 4 presents the results of the multinomial regression model. The model was significant at 1 percent level of significance as shown by the Chi2 (168) =371.25***. The Pseudo R2=0.1396, with a Log-likelihood = -1143.6896. These statistics showed that the model was well fit and specified. The estimated coefficients did not differ significantly across alternative combinations of WMSs.

Table 4: Determinants of the adoption of the individual WMSs.

Variables (Base-$C_0S_0H_0O_0$)	**$C_1S_0H_0O_0$**	**$C_0S_1H_0O_0$**	**$C_0S_0H_1O_0$**	**$C_1S_1H_0O_0$**	**$C_1S_0H_1O_0$**	**$C_0S_1H_1O_0$**	**$C_0S_1H_0O_1$**	**$C_0S_0H_1O_1$**	**$C_1S_1H_1O_0$**	**$C_1S_1H_0O_1$**	**$C_0S_1H_1O_1$**	**$C_1S_1H_1O_1$**
Age	**0.068**** **(0.033)**	**0.056**** **(0.025)**	**0.066***** **(0.025)**	0.002 (0.035)	**-0.137***** **(0.047)**	**0.070***** **(0.024)**	**0.050*** **(0.028)**	**0.066***** **(0.027)**	**0.064**** **(0.029)**	0.040 (0.037)	**0.057**** **(0.026)**	**0.060**** **(0.029)**
Gender	0.663 (0.982)	-0.098 (0.704)	-0.031 (0.693)	0.391 (1.104)	1.585 (1.843)	0.061 (0.692)	0.427 (0.757)	-0.020 (0.766)	0.201 (0.803)	0.579 (1.132)	0.174 (0.728)	0.154 (0.820)
Household size	-0.022 (0.209)	**-0.220*** **(0.125)**	-0.073 (0.113)	-0.009 (0.197)	0.178 (0.178)	-0.152 (0.113)	-0.247 (0.154)	-0.119 (0.126)	**-0.331**** **(0.166)**	-0.064 (0.191)	-0.093 (0.120)	**-0.298**** **(0.145)**
Land size	-1.342 (0.933)	-0.057 (0.160)	-0.125 (0.157)	0.126 (0.197)	0.351 (0.248)	-0.070 (0.154)	-0.248 (0.194)	-0.109 (0.178)	0.074 (0.168)	0.026 (0.245)	-0.150 (0.171)	0.045 (0.188)
Credit Access	1.696 (1.119)	0.286 (0.842)	-0.406 (0.850)	-1.027 (1.268)	0.074 (1.352)	0.519 (0.528)	0.363 (0.887)	-0.381 (0.975)	1.140 (0.904)	1.346 (1.053)	0.884 (0.842)	1.175 (0.913)
Formal education	1.852 (1.384)	**1.446**** **(0.745)**	0.966 (0.719)	**16.626***** **(0.892)**	**14.486***** **(1.033)**	**1.867***** **(0.714)**	0.238 (0.777)	1.180 (0.831)	**1.986**** **(0.968)**	1.181 (1.405)	**1.984***** **(0.824)**	**17.841***** **(0.629)**
Title	-0.531 (0.877)	**0.934*** **(0.597)**	0.647 (0.569)	**1.783*** **(1.027)**	-0.707 (1.213)	**1.358**** **(0.582)**	0.866 (0.657)	**1.252*** **(0.691)**	0.596 (0.667)	0.203 (0.857)	**1.701***** **(0.635)**	1.073 (0.712)
Livestock ownership	-0.362 (1.306)	-1.042 (0.911)	-0.935 (0.893)	-1.759 (1.171)	-0.866 (1.348)	-0.221 (0.900)	-0.843 (0.970)	-0.615 (1.051)	-0.510 (1.066)	-1.336 (1.242)	0.153 (1.000)	-1.531 (1.020)
TLU	0.524 (0.359)	0.368 (0.345)	0.411 (0.341)	0.456 (0.344)	-0.576 (0.688)	0.490 (0.340)	0.476 (0.340)	0.494 (0.340)	0.511 (0.340)	0.482 (0.340)	0.503 (0.340)	0.399 (0.359)
Primary occupation	**18.457***** **(0.686)**	**1.107*** **(0.661)**	**1.231**** **(0.614)**	**2.051*** **(1.240)**	**2.483***** **(1.004)**	**1.499**** **(0.630)**	**1.293*** **(0.765)**	**2.776**** **(1.206)**	1.336 (0.882)	**18.946***** **(0.681)**	0.858 (0.647)	**2.835***** **(1.110)**
WRUA membership	**2.499**** **(1.096)**	**1.477*** **(0.903)**	**0.923** **(0.890)**	**3.138***** **(1.140)**	**1.289** **(1.154)**	**1.049** **(0.891)**	**3.480***** **(0.973)**	**2.044**** **(0.946)**	**1.436** **(0.945)**	**3.164***** **(1.121)**	**2.560***** **(0.919)**	**2.898***** **(1.025)**
Extension source-Govt	0.286 (3.676)	**16.334***** **(1.073)**	**15.719***** **(1.122)**	**18.140***** **(1.131)**	1.349 (1.261)	**16.495***** **(1.014)**	**16.869***** **(1.029)**	**17.210***** **(0.964)**	**15.167***** **(1.227)**	**17.355***** **(1.095)**	**16.904***** **(0.982)**	**16.633***** **(1.107)**
Extension source-Private	-1.009 (1.320)	-1.333 (1.009)	-1.247 (0.998)	-1.287 (1.114)	**-14.83***** **(1.182)**	-1.041 (0.958)	-0.180 (0.991)	-1.038 (1.062)	**-2.226*** **(1.210)**	-2.194 (1.636)	-0.887 (0.981)	-0.637 (1.023)
Extension source-media	**-16.88***** **(1.005)**	0.108 (0.917)	-0.069 (0.894)	1.098 (1.073)	**-15.04***** **(1.131)**	-0.021 (0.890)	-0.369 (0.992)	-0.646 (1.022)	0.094 (0.981)	-0.283 (1.123)	0.401 (0.922)	1.143 (0.962)
Constant	**-23.00***** **(2.761)**	-2.284 (1.815)	-2.193 (1.769)	**-21.05***** **(2.164)**	**-13.36***** **(2.577)**	**-4.519***** **(1.760)**	**-3.406*** **(2.014)**	**-6.273***** **(2.363)**	**-4.844**** **(2.373)**	**-23.11***** **(2.495)**	**-6.025***** **(1.867)**	**-22.900**** **(2.213)**

* Significant at 10%   ** significant at 5%   *** significant at 1%. The figures in brackets are robust standard errors.

The results showed that the age of the household head had a significant effect on the choice of WMS. The results implied that older farmers were more likely to adopt a majority of the different WMS combinations apart from the Cropping and Water harvesting combination ($C_1S_0H_1O_0$), where it was the younger farmers who were most likely to adopt. These findings were consistent with literature since, with age comes experience. The results showed that older famers were quite experienced and used this experience to adopt WMS combinations, which they deemed to have the greatest welfare benefit to the household. These findings were consistent with the findings by (28-29). From previous literature, through experience farmers perceive and understand the problem of soil erosion and the importance of water conservation. Previous, literature (28,30,31) has also shown, that older farmers would not adopt soil and water conservation technologies, like in the case of the $C_1S_0H_1O_0$ combination, this is because, as age progresses, the ability to adopt the WMS combination decreases. This implies that younger farmers were more willing to adopt this combination since the younger farmers were willing to seek more information on improved crops and better water harvesting and storage technologies like water pans with dam liners among other technologies as compared to older farmers.

The household size had a negative and significant influence on the adoption of Soil WMS ($C_0S_1H_0O_0$), cropping, soil, and water harvesting combination ($C_1S_1H_1O_0$) and all the WMS combinations ($C_1S_1H_1O_1$). While, previous research has shown a positive effect of the household size on the adoption of soil and water management techniques due to more household labour reserves (see 28, 32, 33). The findings of this study concur with, previous studies who found a negative influence of the household size on adoption of soil and water conservation technologies (see, 34-35), this negative influence on adoption can be explained to some of the constraints facing larger households, where, first some of the household members could be engaged in non-farming activities or idling and secondly, large households were likely to face food shortage (36).

Formal education has been demonstrated to perform a key role in farm household adoption decisions. From the results, household heads with formal education had a higher probability of adopting all alternative WMS combinations, however it was significant for the adoption of, $C_0S_1H_0O_0$, $C_1S_1H_0O_0$, $C_1S_1H_0O_0$, $C_0S_1H_1O_0$, $C_1S_1H_1O_0$, $C_0S_1H_1O_1$ and $C_0S_1H_1O_1$. These findings reinforced the role of formal education in technology adoption. These finding were consistent with previous studies (15, 16, 28, 32, 33), who found that education influenced adoption behavior of households for SWC technologies. This finding could be explained, since educational level of household head increases, farmers' ability to get and use information, thereby improving farmers' ability to adopt WMS technologies.

Secure land rights and property rights through land titling play a key role in the adoption of technologies at the farm level. The results showed that households holding a title deed for their land had a higher probability of adopting soil WMS ($C_0S_1H_0O_0$), cropping and soil practices combination ($C_1S_1H_0O_0$), soil practices and water harvesting ($C_0S_1H_1O_0$), water harvesting and optimization practices ($C_0S_0H_1O_1$) and the soil practices, water harvesting and water optimization techniques combination ($C_0S_1H_1O_1$). This finding was consistent with previous studies that found that tenure security was related to the adoption of SWM technologies (37-39). The importance of tenure security stems from the long-term nature of the adoption of WMS technologies. From previous studies, tenure security is important to undertake long-term land improvement investments (40). Further, previous empirical findings have shown that farmers were not likely to invest in sustainable resource management on the rented property if the length of use-rights does not allow them to recoup their investments (41-43)

The primary occupation was found to have a positive and significant influence on the adoption of a majority of WMS combinations. This result was consistent with previous literature (44), which found that farmers whose primary occupation was full-time farming were more likely to adopt improved irrigation systems, optimizing available water resources.

Membership to a WRUA was found to have a positive and significant effect on the adoption of all WMS combinations, except for; water harvesting WMS ($C_1S_0H_0O_0$), cropping and water harvesting ($C_1S_0H_1O_0$), soil and water harvesting ($C_0S_1H_1O_0$), and cropping, soil and water harvesting ($C_1S_1H_1O_0$). Previous studies have shown the importance of community-level institutions in the adoption of SWC technologies. Local institutions and groups form an efficient avenue for farmer mobilization, for training, information access and even access to important inputs such as water, credit among others. Previous studies have shown that farmers' groups are avenues for access to information on new agricultural technologies and innovations (44-45). From previous studies, evidence showed that collective action can play a significant role in the adoption of technologies for the conservation and management of contested resources like water (42, 46). The findings of this study concur with findings of (47) and (48), who examined the effects of collective action (membership to a farmer group or association) on the adoption of conservation technologies; their results showed that collective action can enhance adoption of conservation practices by helping farmers address market failures and information constraints.

The source of extension services, finally, mattered as a determinant of the adoption of WMS. According to 42, access to markets and institutional arrangements like access to extension, create incentives to invest in options that expand future production such as resource improving and productivity-enhancing investments. From the results, the most important driver to the adoption of WMS was the government extension services. Government as a source of extension services was found to have a significant and positive influence on the adoption of all the alternative WMS combinations except for the adoption of cropping ($C_1S_0H_0O_0$) and cropping and water harvesting ($C_1S_0H_1O_0$). This finding was consistent with previous findings that have shown the importance of government-led extension provision (15, 16, 36). On the contrary, private extension and media extension was negatively related to the adoption of alternative WMS combinations. This could be explained since the private extension is geared towards a particular goal, which is in line with the provider's mandate. Media as a source of extension has its limitations of access, delivery and consistency which may explain the negative influence on the adoption of WMS technologies.

Impacts of adoption of WMS on household consumption per adult equivalent

The impacts of adoption of the different WMS combinations on household consumption per adult equivalent was examined as shown in table 5.

Table 5: Average Treatment Effects of WMS adoption

WMS alternatives		**Adopters**	**Non-adopters**	**Treatment effect**
$C_1S_0H_0O_0$	Adopters	55833.35	62022.49	ATT=-6189.14
	Non-adopters	548390.4	72296.16	ATU=476094.2***
$C_0S_1H_0O$	Adopters	84574.51	67361.99	ATT= 17212.53***
	Non-adopters	81698.08	70349.25	ATU= 11348.82***
$C_0S_0H_1O_0$	Adopters	59587.39	62076.24	ATT= -2488.846
	Non-adopters	59623.01	74851.61	ATU= -15228.61
$C_1S_1H_0O_0$	Adopters	61548.29	90163.69	ATT= -28615.4*

	Non-adopters	840.7347	72230.04	ATU= -71389.31***
$C_1S_0H_1O_0$	Adopters	33919.74	67422.7	ATT= -33502.96***
	Non-adopters	-75449.36	72304.8	ATU= -147754.2***
$C_0S_1H_1O_0$	Adopters	70159.64	70541.59	ATT= -381.95
	Non-adopters	72085.16	72657.91	ATU= -572.75
$C_0S_1H_0O_1$	Adopters	89097.17	74551.61	ATT= 14545.56**
	Non-adopters	70557.96	70663.72	ATU= -105.76
$C_0S_0H_1O_1$	Adopters	69045.34	68685.23	ATT= 360.12**
	Non-adopters	99971.92	72246.35	ATU= 27725.57***
$C_1S_1H_1O_0$	Adopters	64805.21	79286.62	ATT= -14481.41**
	Non-adopters	94694.32	72438.95	ATU= 22255.37***
$C_1S_1H_0O_1$	Adopters	67042.61	72064.84	ATT= -5022.231
	Non-adopters	321819.1	72119.1	ATU= 249700***
$C_0S_1H_1O_1$	Adopters	81052.97	79947.47	ATT= 1105.50**
	Non-adopters	72635.61	70728.74	ATU= 1906.87**
$C_1S_1H_1O_1$	Adopters	85354.62	84168.43	ATT= 1186.19**
	Non-adopters	5118552	71389.39	ATU= 504716.30***

* Significant at 10% ** significant at 5% *** significant at 1%.

These results guided the study in achieving the second aim of this objective i.e. to determine the impact of the adoption of the alternative WMSs combinations on household welfare measured by consumption per adult equivalent. From the results, it was clear that different WMS combinations had different welfare effects on households. The results showed a mixture of both positive and negative ATT and ATU. The combinations with negative ATT and ATU implied that households would have less consumption per adult equivalent if they adopted any of those combinations. From the results, the ATT for water harvesting only ($C_0S_0H_1O_0$) was found to be -2488.85, this implied that adopters were worse off adopting this combination. Similarly, non-adopters would also be worse off if they adopted this combination since they would forego a HCPAE of 15, 229 if they considered adopting this alternative. The same case applied to the cropping and soil alternative ($C_1S_1H_0O_0$), cropping and water harvesting alternative ($C_1S_0H_1O_0$), and the soil and water harvesting alternative ($C_0S_1H_1O_0$). These findings showed that both adopters and non-adopters with regard to the foresaid WMS alternatives would experience welfare losses and should consider alternative WMS alternatives to improve their welfare.

Further, some combinations showed mixed effects with regard to ATT and ATU. For instance, the ATT of the adopters of the cropping strategy only ($C_1S_0H_0O_0$), was -6189, implying that even though they had adopted cropping strategies, they were not as efficient and therefore were losing KES 6189, what this implied in essence was that, these farmers would have been better off if they considered another WMS strategy combination to improve welfare. On the contrary, non-adopters of the cropping strategy ($C_1S_0H_0O_0$) stood to gain more if they considered adopting improved crops (to the tune of 476094 annually). This finding was consistent with literature on the importance of the adoption of improved crops on household welfare (11, 49) these studies have shown positive impacts of the adoption of improved crop varieties on household consumption.

The other WMS combination with mixed findings was the soil and water optimization strategy ($C_0S_1H_0O_1$), whereby, the ATT for the adopters was found to be KES 14545, implying that households adopting this combination had an impact of about KES 14500, in terms of HCPAE. On the contrary, the ATU, showed that, this figure although marginal, if non-adopters considered adoption of this combination ($C_0S_1H_0O_1$), they would forego, a HCPAE value of KES 105.76 annually. Further, the cropping, soil and water harvesting combination ($C_1S_1H_1O_0$), also showed mixed impacts whereby, the ATT of adopters showed that, while they had adopted this combination, it resulted in a welfare loss of KES. 14481 in HCPAE terms. The resulting inefficiency could have arisen from the lack of optimization of the available water resources, so as to make the best use of the available water resources, which would have resulted in a welfare gain for the household. On the contrary, the ATU, showed that non-adopters would, have achieved better welfare, with an additional of KES. 22,255 in HCPAE terms if they considered adoption. A similar scenario applied, for the cropping, soil, and water optimization alternative ($C_1S_1H_0O_1$), whereby, the ATT for the adopting households was negative, implying that households, had a welfare loss of KES 5022 in HCPAE terms. On the contrary, the ATU showed that if non-adopters considered taking, up the same strategy ($C_1S_1H_0O_1$), they could have achieved welfare gains of upwards of KES 249,700 in HCPAE terms. These two combinations could be considered for non-adopters or for the households adopting WMSs combinations that produce welfare-reducing outcomes as discussed above, since, adoption theory, has shown that adoption of farm technologies is rather gradual and dependent on a set of socioeconomic and institutional factors.

Finally several combinations had positive outcomes in terms of both, ATT and ATU. From the results, adoption of soil technologies only had positive outcomes for households. The ATT showed that adopters would have lost KES. 17,212 in HCPAE terms, if they had not considered adopting this strategy. Further, the ATU showed that, if non-adopters considered adopting this strategy, they could have achieved an increased welfare of KES. 11,348 in HCPAE terms. The results further showed that water harvesting would have worked well if and only if it was used in combination with water optimization technologies to improve household welfare. From the results, the water harvesting and water optimization alternative ($C_0S_0H_1O_1$), had an ATT of KES. 360, implying that, adopters had, a better welfare of KES 360 more in HCPAE terms, as compared to the situation if they did not adopt. The ATU showed that if non-adopters considered, adopting this combination ($C_0S_0H_1O_1$), they could obtain welfare gains of KES. 27,725 in HCPAE terms. Finally, adoption of a combination comprising all the WMS ($C_1S_1H_1O_1$), resulted in the greatest welfare gains for households. The results showed that the ATT of households that adopted all the WMS, was KES 1186 in HCPAE terms. This implied that households were better off adopting all the WMS combinations than just a few. The ATT was quite low implying that adopters could have generated better welfare gains through intensive use of all the WMSs in each category. The ATU showed that, non-adopters stood to gain, KES 504,716 more in HCPAE terms, if they considered adoption of all WMS categories. This findings reinforced previous studies that found a positive impact of adoption of SWC technologies on household welfare (15, 16, 47, 48, 50).

Conclusions and Recommendations

The objective of this study was to assess the determinants of the adoption of WMS technologies, and the impact of the alternative WMS combinations on household welfare. Results showed that adoption of alternative WMS combinations was influenced by the age of the household head, WRUA membership, household size, formal education, holding a title deed, the primary occupation of the household head and the source of extension services. The impact assessment results showed that farmers who adopted different WMS strategies would have different welfare impacts in terms of household consumption expenditure per adult equivalent. From the results, the combinations that left both adopters and non-adopters worse-off included: water harvesting only ($C_0S_0H_1O_0$); cropping and soil alternative ($C_1S_1H_0O_0$); cropping and water harvesting alternative ($C_1S_0H_1O_0$); and the soil and water harvesting alternative ($C_0S_1H_1O_0$). The results also showed that some combinations had mixed welfare impacts, in two cases; first was the case where adopters had a negative ATT and non-adopters, would have had a positive ATU if they chose to adopt the alternatives. These included; cropping strategy only ($C_1S_0H_0O_0$); the cropping, soil and water harvesting combination ($C_1S_1H_1O_0$); the cropping, soil, and water optimization alternative ($C_1S_1H_0O_1$). The second case is where the ATT for the adopters was found to be positive and ATU for non-adopters was found to be negative, these alternatives included; soil and water optimization strategy ($C_0S_1H_0O_1$) only. Finally, different combinations resulted in positive welfare outcomes for both adopters (ATT) and non-adopters if they considered adopting (ATU). These welfare optimizing alternatives included; adoption of soil technologies only ($C_0S_1H_0O_0$); the water harvesting and water optimization alternative ($C_0S_0H_1O_1$); and the adoption of a combination comprising all the WMS ($C_1S_1H_1O_1$), would result in the greatest welfare gains for households. Therefore, the following policy recommendations are prescribed for policy makers. The results have shown that adoption of on-farm water management strategies, is influenced by household socioeconomic and institutional factors. Key among them source of extension, and formal education. Results have shown that adoption of all WMS offers the greatest impact on household welfare. Therefore, households need to be trained on the importance of the adoption of multiple water management strategies so as to benefit from substitutionality and complementarity of these technologies.

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Conflicts of Interests

The authors declare no conflict of interest

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