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Determinants of adoption of rainwater-harvesting technologies in a rain shadow area of southern Malawi

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Abstract

This paper examines determinants of the adoption of rainwater-harvesting technologies in a rain shadow area of southern Malawi. The most common ex situ technologies in the area were dams, and the widely used in situ technologies were box ridges, contour markers and swales. Adopters treated, on average, 80% of their farms with the rainwater-harvesting technologies, a move that significantly increased their food security status and incomes. The key finding of the study is that the choice of technologies was influenced by land slope and quality, farm size, soil texture, security of land tenure, education level of household head and extension support. The results therefore underscore the potential gains from rainwater-harvesting technologies in improving farmer income and food security, and the need to promote the technologies as a package, because a household may implement different technologies on the same field depending on diverse social, economic, institutional and environmental factors.

Key words: adoption; Malawi; rain shadow area; rainwater harvesting; technology

1. Introduction

Most people in Malawi are living in areas where water and rainfall are limited and very irregular. The rainfall is limited because it falls only in six months of the year, leaving farmers with half of the year without rain. The rainfall has been irregular in recent times – to such an extent that farmers are now experiencing dry spells even in the middle of the supposedly rainy season. This is happening on top of other problems, such as the tremendous population growth, global warming, the HIV/AIDS pandemic and competition for water between agriculture and urban areas. These problems have led to water shortages and land degradation, with the final consequence of poverty, which manifests itself in the form of low levels of nutrition, poor sanitation, a low level of hygiene, a lack of safe water, poor health status, dependency, insecurity, migration to cities and desperation (Imani Development 2004; Department of Irrigation 2011).

Smallholder farmers account for almost 90% of the Malawian population. During good years, agriculture, which is the mainstay of these farmers, produces good yields when external inputs such as fertiliser and chemicals are applied. However, when reduced rainfall or prolonged dry spells are experienced, it leads to immediate crop failure, food insecurity and massive suffering amongst the majority of rural people. Irrigation agriculture would be a logical solution to this, but water scarcity, inappropriate terrain and the high cost of irrigation infrastructure are major handicaps. Some irrigation technologies, such as treadle pumps, flood irrigation and drip irrigation, have been adopted, but these are used by less than 5% of the farming population. Alternative solutions should be pursued to increase the quantity of water on farmers' fields so that crop production is not affected. This will improve food security for the poor (Department of Irrigation 2011).

Water harvesting is a proven technology for increasing food security in drought- or dry spell-prone areas. Rainwater harvesting is the collection and use of precipitation from a catchment surface for domestic, livestock, agricultural and other uses. It is the process of concentrating, collecting and storing water for different uses at a later time in the same area in which the rain falls, or in another area during the same or later times (Li *et al*. 2000; Tesfay 2008; Njoloma 2011).

Rainwater harvesting is essential for five main reasons. First, surface water is inadequate to meet people's demands and they then have to depend on ground water. Second, due to rapid urbanisation, the infiltration of rainwater into the subsoil has decreased drastically and the recharging of ground water has diminished. Third, the nature of the rainfall in Malawi is such that, if not managed, it quickly evaporates or runs as 'flash floods' into saline sinks. Fourth, collecting rainwater not only conserves water, but also conserves energy, since the energy input required to operate a centralised water system and to pump water over a vast service area is bypassed. Fifth, rainwater harvesting lessens local soil erosion and flooding caused by runoff from impervious cover, as some rain is instead captured and stored. Thus, stormwater runoff, which picks up contaminants and degrades waterways and is a normal consequence of rainfall, becomes captured rainfall, which can then fulfil a number of productive uses such as the irrigation of crops during dry spell or dry periods (Texas Water Development Board 1997; Department of Irrigation 2004).

Quite a number of studies have been carried out on the adoption of other technologies, but to the best of our knowledge none have looked at factors that influence the adoption of rainwater-harvesting technologies in Malawi (Njoloma 2011). In other countries, such as China, Li *et al.* (2000) noted that technological, agro-hydrological, ecological, social, cultural, economic and political factors are important in spreading rainwater-harvesting technologies over large areas. The rainwater-harvesting technologies should also be effective and affordable, and there should be social institutions and policy instruments that facilitate the adoption of the rainwater-harvesting technologies for agriculture. In Ethiopia, Tesfay (2008) showed that poor capital and human endowment, lack of access to credit, involvement in off-farm activities, negative perceptions, gender issues and technical issues were among the factors that negatively influenced the adoption of rainwater-harvesting technologies. On the other hand, level of education and involvement in social responsibilities positively influenced the adoption of the technologies.

Judging by the immense contribution rainwater-harvesting technologies can make to a rural society, a study on the determinants of the adoption of rainwater-harvesting technologies in Malawi becomes timely. Adoption rates of rainwater-harvesting technologies are far lower than expected because of the difficulties associated with the many combinations of ecological and socioeconomic constraints that exist in rural areas (He *et al*. 2007). It is therefore important to assess the social, economic, environmental and institutional factors that would encourage farmers in Malawi to adopt rainwater-harvesting technologies. This knowledge would help policy makers to devise appropriate strategies for promoting rainwater harvesting to enhance food security at the household level in the country.

To understand and explain why some farmers in the study area adopt rainwater-harvesting technologies while others do not, the paper had the following specific objectives: (1) to generate an inventory of rainwater-harvesting technologies in the rain shadow area; (2) to assess farmers' perceptions of rainwater-harvesting technologies in the area; and (3) to assess social, economic, environmental and institutional factors that influence the subsequent adoption of rainwater-harvesting technologies in the rain shadow area. Connected to these objectives, the study tested the following hypotheses: (1) farmers do not perceive any benefits from adopting rainwater-harvesting technologies; and (2) socio-economic, environmental and institutional factors have no influence on the adoption of rainwater-harvesting technologies.

The rest of the paper is organised as follows. Section 2 presents the methodology, with an emphasis on description of the tobit and nested logit models applied in the study. Section 3 is devoted to rainwater-harvesting issues and presents the results of the tobit and nested logit models. Section 4 draws conclusions and makes key policy recommendations.

2. Methodology

2.1 Research site and data collection

The study targeted a rain shadow area of the Zomba Rural Development Project (RDP) in the Machinga Agricultural Development Division (ADD) in the Southern region of Malawi. This particular ADD, one of the eight ADDs in Malawi, was chosen because it has the most potential for rainwater harvesting. This potential arises from the presence of high rainfall areas, dry spell-prone areas and gravity-fed irrigation from Zomba Mountain. Consequently, the RDP represents an area where rainwater-harvesting initiatives can be the most rewarding for both domestic water supply and agricultural use to reduce poverty and food insecurity (Clarke 2004). The study specifically targeted the Chingale Extension Planning Area (EPA), which is a rain shadow area located on the western side of Zomba Mountain adjacent to the Shire River – a key outlet of Lake Malawi. Primary data was collected from three sections of the Chingale EPA that were purposely selected because they had a high proportion of farmers practising rainwater harvesting. The study team generated an inventory of all rainwater-harvesting technologies in the three sections and determined the most common rainwater-harvesting technologies currently in use in the area.

2.2 Sampling of smallholder farmers

The smallholder farmers, as units of inquiry, were in the first stage stratified into adopters and non-adopters using sampling frames obtained from the individual sections. The adopters were those farmers who were either practising one rainwater-harvesting technology, or a combination of two or more technologies, on their farms. Another criterion for choosing an adopter was intensity of use of the technologies for a period of not less than three years.

In the second stage, the adopters were stratified into technology bundles. Since women carry out most agricultural activities in Malawi, the adopters in the technology bundles and the non-adopters were further stratified in the third stage of the study into male-headed and female-headed households (gender consideration). In the fourth and final stage, 213 adopters and 51 non-adopters were randomly selected to form the final sample of 264 households. Random samples were taken from each stratum.

2.3 Inventory of rainwater-harvesting technologies in the Chingale EPA

Through interviews and field visits, the study team compiled an inventory of all rainwater-harvesting technologies currently being practised in the Chingale EPA. Frequencies and percentages were used to describe the proportion of farmers using each technology, as well as the extent of use of each of the technologies. A number of rainwater-harvesting technologies are being practised in Malawi. The technologies include *ex situ* technologies, such as tanks (both aboveground and underground), ponds and dams, as well as *in situ* technologies, such as terracing, swales and box ridges. *Ex situ* technologies are structures that are built as water reservoirs for harvested rainwater, while *in situ* technologies involve storing harvested rainwater in the crop field exactly where the water is needed.

2.4 Empirical model

2.4.1 Tobit model of rainwater-harvesting technologies

To model perceptions, we followed Adesina and Baidu-Forson (1995) and considered that a smallholder farmer i perceives to obtain a benefit $\pi(c)$ from adopting a rainwater-harvesting technology and a benefit $Z(t)$ from a traditional practice. In the context of the smallholder farmer, the benefit is assumed to be increased farm income and/or food security. The smallholder farmer i is assumed to have perceptions of technology-specific characteristics. Let the perceptions be represented by M_{ic} and P_{it} for the rainwater-harvesting and traditional technologies respectively. For simplicity, let R represent socio-economic and demographic factors. Thus,

$$\pi_{ci} = f(M_{ic}, P_{it}; R_i) \ and \ Z_{ti} = g\left(M_{ic}, P_{it}; R_i\right). \tag{1}$$

To understand this relationship better, a tobit model is used, as shown below:

$$A_i^* = \beta X_i + \varepsilon_i \tag{2}$$
$$A_i = 0 if A_i^* \leq 0 \rightleftarrows \tag{3}$$
$$A_i = A_i^* if \rightleftarrows A_i^* > 0, \tag{4}$$

where A_i represents what the smallholder farmer perceives to be the benefit associated with the rainwater-harvesting technology; A_i^* is the latent variable that indexes the adoption of the rainwater-harvesting technology; X is a vector of socio-economic, demographic and perception variables; β is a vector of parameters to be estimated; and ε is a stochastic error term (Adesina & Baidu-Forson 1995).

Using this notation, a two-technology comparison is given by $\pi_{ic} - Z_{it} > 0$, and this implies that $A_i^* > 0$. This shows that the farmer will adopt the rainwater-harvesting technology because it increases farm income and/or food security beyond the traditional technology. Under these circumstances, $A_i^* = A_i$. When the smallholder farmer does not adopt the rainwater-harvesting technology we have $\pi_{ic} - Z_{it} \leq 0$. This means that $A_i = 0$.

The dependent variable for the tobit model was the share of farmland under rainwater-harvesting technology (Lowenberg-DeBoer 2000). This being a censored dependent variable, a logit or probit model is inappropriate for this study (Adesina & Baidu-Forson 1995; Maddala 1997, 2002). Explanatory variables included the farmers' perceptions of the technology. Farmers adopt technologies based on their perceptions of the attributes of the technology, especially when compared with their own, current practices. The study critically assessed farmers' perceptions of specific attributes of the interventions, especially their perceptions of water efficiency and ease of application. The other key variables that were investigated include socio-economic variables and farm plot characteristics. Perception was measured by asking farmers to compare the introduced rainwater- harvesting technologies (i.e. whether better, same or worse) with their current practices. For use in the regression analysis, the perceptions were coded as 1 for better and 0 otherwise. The choice of perception variables follows Adesina and Baidu-Forson (1995) and Mangisoni and Bokosi (2004).

Other explanatory variables that were considered were slope of field and soil type and texture (environmental factors), farm size, education, household size, gender, farm income (socio-economic factors); and extension frequency, access to credit and security of land rights (institutional factors) (Shiferaw 1997; Mangisoni 1999). Farm income was measured as the net crop farm income in Malawi Kwacha. It was hypothesised that cash cropping and farm income would have a positive relationship with the dependent variable. Education and extension frequency were expected to be positively related to adoption, because farmers tend to be more aware and exposed to new technologies (Adesina & Baidu-Forson 1995; Mangisoni & Bokosi 2004).

2.4.2 Nested logit model of rainwater-harvesting technologies

Farmers were assumed to be faced with multiple rainwater-harvesting technologies from which to make a choice, and that the choices could be made sequentially. A nested multinomial logit model was used to address this issue. The nested multinomial logit model was chosen in order to accommodate the fact that a smallholder farmer may choose a rainwater-harvesting technology on one field and a technology that does not harvest rainwater on another field because of field-specific characteristics. To model this we followed Maddala (1997, 2002) and considered a smallholder farmer who is faced with a problem related to the choice of a technology, with a choice of locations (fields) that are indexed $i = 1, 2, \ldots, L$ and rainwater-harvesting technologies that are indexed $j = 1, 2, \ldots\ldots, T_i$ in location i.

We assumed that the smallholder farmer will have a utility U_{ij} for alternative (i, j). Then, let U_{ij} be a function of the attributes of these alternatives, such as environmental factors, institutional factors and the farmer's socio-economic characteristics. The smallholder farmer will tend to choose the technology that maximises his/her utility. Let $U_{ij} = V_{ij} + \varepsilon_{ij}$, where V_{ij} is a function of all the measured characteristics and ε_{ij} is a residual that captures the effects of unmeasured variables, personal idiosyncrasies, imperfections in perception and maximisation, and so on. Assuming that ε_{ij} is independently and identically distributed with the extreme-value distribution (Maddala 1997, 2002), then the probability, P_{ij}, that the *(i,j)th* alternative will be chosen is given by

$$P_{ij} = \frac{e^{v_{ij}}}{\sum_{m=1}^{L}\sum_{n=1}^{Tm} e^{V_{mn}}} \tag{5}$$

Suppose that

$$V_{ij} = \beta' X_{ij} + \alpha' Z_i, \tag{6}$$

where X_{ij} is a vector of observed attributes that vary with both technology and location, Z_i is a vector of attributes that vary only with location (e.g. gentle slope, steep slope), and α and β are vectors of unknown parameters.

Let $P_{ij} = P_{j/i} . P_i$ (7)

The conditional probability, $P_{j/i}$, can be seen to be

$$P_{j/i} = \frac{e^{V_{ij}}}{\sum_{k=1}^{T_i} e^{V_{ik}}} = \frac{e^{\beta' X_{ij}}}{\sum_{k=1}^{T_i} e^{\beta' X_{ik}}} \tag{8}$$

and

$$P_i = \frac{e^{\alpha' Z_i \sum_{j=1}^{T_i} e^{\beta' X_{ij}}}}{\sum_{m=1}^{L} e^{\alpha' Z_m} \sum_{n=1}^{T_m} e^{\beta' X_{mn}}} \tag{9}$$

We define an inclusive value as

$$I_i = \log\left(\sum_{j=1}^{T_i} e^{\beta' X_{ij}}\right). \tag{10}$$

Then we can write equations (8) and (9) as follows:

$$P_{j/i} = \frac{e^{\beta' X_{ij}}}{e^{I_i}} \tag{11}$$

$$P_i = \frac{e^{\alpha' Z_i + I_i}}{\sum_{m=1}^{L} e^{\alpha' Z_m + I_m}} \tag{12}$$

The technique for estimating equation (5) is to estimate the parameters β from the conditional-choice equation (8), calculate the values, I_i, and finally estimate α from equation (12), given the values of I_i. This sequential approach can be applied in all problems in which the number of choices is very large but the decision process has a tree structure (Maddala 1997, 2002).

A three-level nested logit was estimated in this study to determine factors affecting the sequential adoption of rainwater-harvesting technologies. At the first level, famers choose whether to adopt or not to adopt rainwater-harvesting technologies. At the second level of estimation, farmers choose to adopt either an *ex situ* technology or an *in situ* technology on their farm plots. The farmers finally choose to adopt the actual rainwater-harvesting technologies at the third level of estimation. In this study, dam was the only common *ex situ* technology, and contour makers, ridges and swales were prevalent *in situ* technologies.

Following Li *et al.* (2000) and Tesfay (2008), the key variables that were investigated were socio-economic factors (age of farmer, household size, education, gender and farm size), institutional factors (extension, access to credit, land rights or security of tenure), and environmental factors/field-based characteristics (slope, soil type, land-use intensity or land pressure). Age was measured in years, and education in years of completed schooling. Gender was measured as a dummy variable, taking on the value of 1 for a male household head and 0 for a female household head. Farm size was measured in acres. It was hypothesised that all four socio-economic variables would be positively related to the choice of rainwater-harvesting technologies.

Extension was taken to be the frequency of contacts (proxy for teachable moments) the smallholder farmers had with extension agents (5 = once a week, 4 = every fortnight, 3 = once a month, 2 = twice a year, 1= rarely, 0 = no contact). Access to credit was treated as a dummy variable, taking on the value of 1 for access to credit and 0 for no access to credit. Security of land rights was also treated as a dummy variable, taking the value of 1 if the farmer felt that he/she had security and 0 if there was no security. Security of land rights was measured at the field level, because bundles of property rights might vary across fields on a farm. It was hypothesised that all three institutional variables have a positive relationship with the choice of technologies.

Environmental factors included soil quality, topography and land-use intensity. Land quality was a dummy variable (1 = good soil fertility and 0 = poor soil fertility), and soil texture was identified in terms of the coarseness of the soil (1 = sandy soil, 2 = loam soil, 3 = clay soil). Topography was measured as slope (1 = gentle slope, 2 = moderate slope and 3 = steep slope). Land-use intensity was measured as years of continuous cultivation of fields. It was hypothesised that farmers would tend to implement rainwater-harvesting technologies on land of a good quality because they see the benefit arising from additional water for such land. It was also hypothesised that the farmer would rather choose to implement rainwater harvesting on steeper slopes and less so on gentle slopes and in valleys.

Environmental factors were included to capture field-specific characteristics (He *et al.* 2007). Resource management technologies such as rainwater harvesting are specific in that their adoption depends on the characteristics of each field on the same farm. The smallholder could be an adopter for one of his/her fields that needs supplemental water and a non-adopter for another field where there is no need to adopt any rainwater-harvesting technology. Thus, it is important to include environmental factors in the model in order to eliminate a bias in the understanding of the adoption process. In line with this observation, a parameter on land pressure was added. The data on land quality, topography and land pressure was field based and not smallholder farmer based. In other words, environmental factors were measured on the fields. Stata econometric software was use for the econometric analyses.

3. Results and discussion

3.1 Socio-economic characteristics of sample households

Table 1 presents some socio-economic characteristics of sample households that had a significant influence on both the adoption and intensity of use of rainwater-harvesting technologies. The gender of the household head is one of the factors that may influence decisions to adopt rainwater-harvesting technologies. According to Tesfay (2008), it is important to look at the impact of rainwater-harvesting techniques in relation to the gender of the household head. The results show that most adopter and non-adopter households were headed by men. The proportion of male-headed households among the adopters was 63.91% and was almost the same as the proportion in the non-adopter (62.75%) category. These results are consistent with the averages for the Zomba rural area, as reported by the National Statistical Office ([NSO] 2012), which indicated that 28.8% and 71.2% of the households in the Zomba rural area were female and male headed respectively. The high p-values confirm that there is no difference in the proportion of adopters and non-adopters in each gender category.

The results relating to marital status indicate that large proportions of both adopters (73.24%) and non-adopters (84.32%) were married. The difference in proportions of adopters and non-adopters among married household heads was significant at the 5% level. Of the adopters, 9.86% were divorced and 11.74% were widowed, compared to 3.92% and 9.80% of non-adopters in the respective categories.

No significant difference in the proportion of adopters and non-adopters in the different age categories was observed, except for the 21- to 30-year and 51- to 60-year age groups. The mean age of the household head for adopters was 44 years, while for non-adopters it was 41 years. However, the difference in the mean age between the two categories was not significant. According to Tesfay (2008) and He *et al.* (2007), the adoption of various rainwater-harvesting techniques and their uniqueness to different age groups can be attributed to the groups' understanding of their environment and the anticipated benefits of the respective techniques.

Table 1: Socio-economic characteristics of the sample households

Variable	Adopters (%)	Non-adopters (%)	P-value
Gender of household head			
Female	37.09	37.25	0.496
Male	62.91	62.75	0.496
Marital status of household head			
Divorced	9.86	3.92	0.089
Married	73.24	84.32	0.050
Never married	3.29	0.00	0.095
Separated	1.88	1.96	0.484
Widowed	11.73	9.80	0.348
Age category (years)			
15 – 20	2.35	0.00	0.109
21 – 30	21.60	31.37	0.069
31 – 40	23.47	27.45	0.129
41 – 50	20.66	15.69	0.212
51 – 60	15.96	7.84	0.069
Mean age	44.16 (1.02)	41 (2.06)	0.173
Household size			
Mean household size	4.89 (0.14)	5.89 (0.27)	0.068
Education level			
Form 3-4	5.16	7.84	0.230
Form 1-2	6.1	17.65	0.004
Standard 5-8	35.68	27.45	0.134
Standard 1-4	35.22	29.41	0.218
None	17.84	17.65	0.488
Plot size and distance			
Plot size (acres)	1.011 (0.033)	0.956 (0.060)	0.496
Mean distance from home to plot (metres)	732.496 (32.921)	801.783 (85.453)	0.410

Source: Calculated from own survey data

Household size represents a pool of labour that is available to a household for various activities, including farming. Larger households are expected to be more likely to adopt a new technology compared to smaller households, especially if the technology requires additional labour. The study shows that adopters had a mean household size of five members, which was smaller than that of non-adopters. The difference in household size between adopters and non-adopters is significant at the 10% level. Level of education is another important factor related to the adoption of conservation structures, in that literate farmers are in a better position to learn new technologies and use them in a way that contributes positively to the outcomes of their farm production. Education can expose a farmer to information that is necessary to change his or her attitude and increase awareness of a new technology (Adesina and Baidu-Forson 1995; Mangisoni & Bokosi 2004; Tesfay 2008). This study has shown that large proportions of both adopters and non-adopters have some formal education, with most household heads having attained some primary school education.

3.2 Percentage of farmer plots using different rainwater-harvesting technologies

Figure 1 shows that adopters mostly adopted the use of box ridges on their farm plots. The other commonly adopted rainwater-harvesting technologies were contour markers and swales, which accounted for 26.35% and 16.22% of plots respectively. Other rainwater-harvesting technologies included dams, terraces, tanks, compost manure use, ponds, and the use of crop residues.

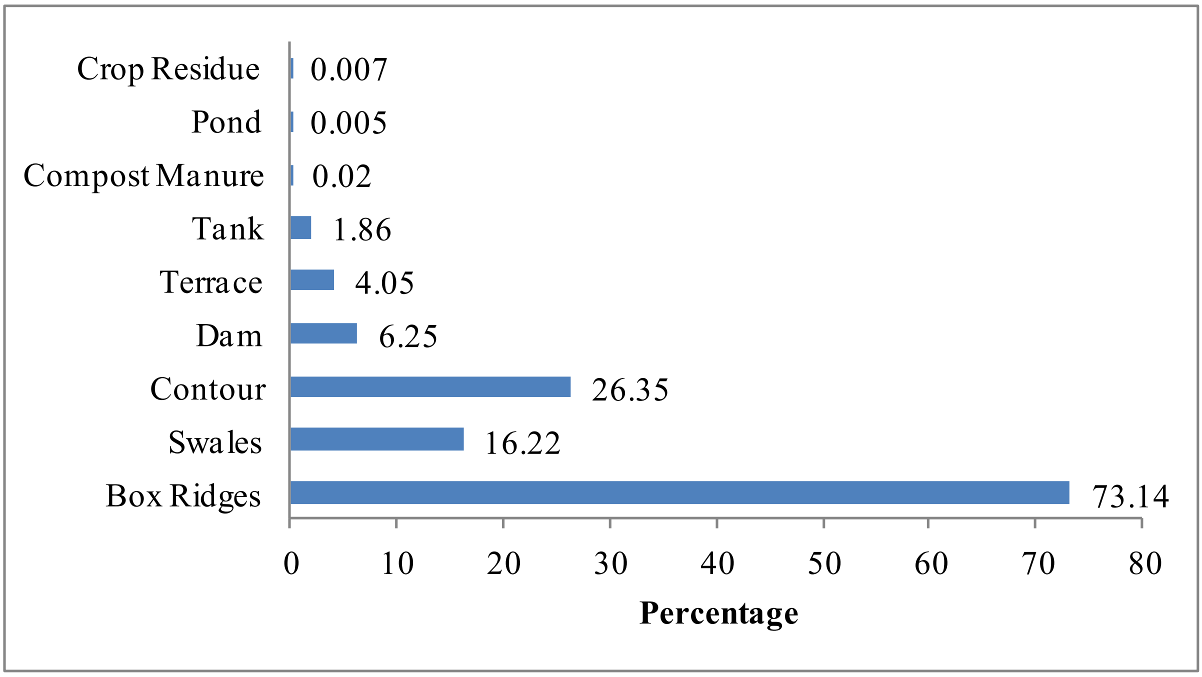

Figure 1: Percentage of farmer plots using different rainwater-harvesting technologies
Source: Calculated from own survey data

3.3 Intensity of adoption of rainwater-harvesting technologies on farm plots

As shown in Table 2, mean farm area for different rainwater-harvesting technologies ranged from 0.62 acres to two acres, with the highest acreage of land (two acres) registered for farmers using crop residuals. Mean area with rainwater-harvesting technology was also high for box ridges (0.91 acres), swales (0.81 acres) and contours makers (0.84 acres). In terms of ratio of area with rainwater- harvesting technology to cultivatable plot size, the mean ratio was above 80% for contour makers, terraces, box ridges, dams and swales. This shows that the adopters tended to treat large areas of their farms with rainwater-harvesting technologies.

Table 2: Intensity of adoption of rainwater-harvesting technologies on farm plots

Technology	Mean area with rainwater-harvesting technology (acre)	Ratio of area with rainwater-harvesting technology to plot size
Box ridges	0.91	0.94
Swales	0.81	0.83
Contour	0.84	0.96
Dam	0.51	0.90
Terrace	0.62	0.95
Tank	0.52	0.65
Compost manure	0.68	1.00
Pond	0.20	0 .46
Crop residue	2.0	0.67

Source: Calculated from own survey data

3.4 Results from the empirical models

3.4.1 Tobit model results

Table 3 gives the results of the tobit analysis of the adoption of rainwater-harvesting technologies. The model has a likelihood ratio chi-square of 312.77 (df = 13), with a p-value of 0.0000. Therefore, the hypothesis that the exogenous variables included in the model have zero influence on the extent of adoption is rejected at the zero-probability level. Statistically significant variables are tenure security, land size, household size, gender of household head, frequency of extension visits, income, perception of ease of operation, perception of ease of maintenance and perception of cost (cheap to use). Security of land tenure has a positive effect on the intensity of use of rainwater-harvesting technologies, which was expected. This shows that farmers' perceptions that their farm plot is secure increases the likelihood of their intensified use of rainwater-harvesting technologies. The other variables that have a positive influence on the intensity of use of rainwater-harvesting technologies were gender of household head and perception that the rainwater-harvesting technologies were easy to operate. The positive relationship between choice of technologies and perception factors is consistent with the findings of Adesina and Zinnah (1993), Adesina and Baidu-Forson (1995), Baidu-Forson (1999), Mangisoni and Bokosi (2004) and He *et al.* (2007), who have also shown that a farmer's positive attitude towards technologies has a significant impact on the probability of adoption.

Land size and household size have a negative relationship with intensity of use of rainwater-harvesting technologies at the 1% level of significance. The implication of this finding is that farmers whose land is small are likely to adopt new technologies to maximise the utilisation of their small farm plots. Likewise, household size, income and frequency of extension visits have negative coefficients. The negative coefficient on frequency of extension visits and education was unexpected. This finding may be due to the fact that the tobit model aggregated all the technologies that were adopted. The negative sign on education might be due to the migration of young educated individuals to cities because they want to leave the less educated to work on the farms (Imani Development 2004).

Table 3: Parameter estimates of tobit model

	Parameter estimates		
Variable	**Estimated coefficient**	**Std. error**	**t-statistic**
Tenure security	0.088962	0.064668	1.38
Soil texture	-0.0531	0.049103	-1.08
Slope	0.010464	0.029802	0.35
Land size	-0.24433***	0.018911	-12.92
Household size	-0.02622***	0.008812	-2.98
Gender of head	0.085283**	0.038485	2.22
Education	-0.00473	0.005494	-0.86
Extension frequency	-0.05102***	0.018653	-2.74
Access to loan	-0.04816	0.061544	-0.78
Income	-4.17E-06***	9.79E-07	-4.26
Ease of maintenance	0.342415***	0.075946	4.51
Easy to operate	0.180501***	0.052868	3.41
Cheap to use	0.296217***	0.074464	3.98
Constant	1.504849***	0.130936	11.49

Log likelihood = -152.44506 , LR Chi^2 (17) = 312.77 (0000), pseudo R^2 = 0.5064
*** significant at 1%, ** significant at 5%
Source: Calculated from own survey data

3.4.2 Nested logit model results

The nested logit model was estimated to examine different factors that affect decisions at different levels of adopting rainwater-harvesting technologies. The independence of irrelevant alternatives (IIA) test statistic was 27.54 and highly significant, indicating that a nested logit model was favoured over a conditional logit model. A three-level nested model was estimated to assess factors affecting sequential choices made by farmers as they adopt rainwater-harvesting technologies. At the topmost level of choice, farmers decided whether or not to adopt rainwater-harvesting technologies. Once a farmer had decided to adopt rainwater-harvesting technologies, decisions were made sequentially to either adopt *ex situ* or *in situ* rainwater-harvesting technologies. Later, the farmer would decide which *ex situ* and *in situ* rainwater-harvesting technologies to adopt. Based on the sources of water collected, the *in situ* and *ex situ* are the two main categories of rainwater-harvesting technologies available to farmers (Barron 2009).

The first-step equation, which gives the likelihood of adopting rainwater-harvesting technologies, showed that household size, gender of household head, marital status and income were important factors that influence the decision to adopt rainwater-harvesting technologies (Table 4). Household size and the marital status of the household head negatively influenced the decision to adopt rainwater-harvesting technologies. The relationship between household size and the adoption of rainwater-harvesting technologies is significant at the 1% level, and between household size and the marital status of the household head is significant at the 5% level. The gender of the household head and farm income have a significant and positive relationship with the adoption of rainwater-harvesting technologies at the 1% level. The implication of these findings is that household socio-economic characteristics have different influences on the decision to adopt and, as such, they need to be considered at level one of adoption for an intervention on rainwater-harvesting technologies to give rise to successful results.

The analysis in the second step of the decision-making equation shows that soil texture and frequency of extension contact have an influence on the choice of technology type: *ex situ* technologies or *in situ* technologies. Soil texture has a negative influence on the choice between the two types of technology, and this relationship is significant at the 1% level. Extension frequency has a significant and positive relationship with the choice of both types of technologies. The coefficient estimate for extension is consistent with the findings of Kalineza *et al.* (1999). The results point to the need for frequent contact between farmers and extension officers to promote the adoption of rainwater- harvesting technologies.

Factors that have an influence on the choice of third-level alternatives are education, slope of land, land quality, land size, farmer's perception of security of land tenure, number of years of cropping on a farm, and soil quality. Years of schooling have a significant and negative relationship with choice of contour makers at the 1% level. This is unexpected, because education may assist to increase awareness of a new technology and thereby increase the capacity of the farmers to apply a given technology. However, from Table 1 it can be seen that there was no significant difference between adopters and non-adopters as far as education was concerned. In actual fact, non-adopters had an edge over adopters in the Form 1 to 2 category. Slope was negatively related to the adoption of contour ridges and swales. This relationship is significant at the 1% level. The implication of this is that the likelihood of adopting swales and contour ridges decreased with a reduction in the slope of the land, and hence with a reduction in water loss on the crop field. This is consistent with the findings of Chiputwa *et al.* (2011).

Table 4: Parameter estimates of the nested logit model

			Parameter estimates		
Level	**Equation**	**Variable**	**Coefficient**	**Standard error**	**Z**
One	Adoption	Household size	-0.4028258***	0.0726226	-5.55
		Gender	0.6258971*	0.3518616	1.78
		Marital status	-1.172906***	0.4299028	-2.73
		Loan	-0.6367605	0.5414245	-1.18
		Income	0.0008907***	0.0001688	5.28
Two	*Ex situ* technology	Soil texture	-1.240221***	0.1855244	-6.68
		Extension	0.3455491**	0.1460145	2.37
Two	*In situ* technology	Soil texture	-0.5567198***	0.1931504	-2.88
		Extension	0.3377479***	0.0867303	3.89
Three	Contour maker	Education	-0.1048599***	0.0363303	-2.89
		Land size	-0.0307601	0.1945672	-0.16
		Land security	-0.4095094	0.3473566	-1.18
		Slope	-0.8634551***	0.1962332	-4.40
		Crop year	0.0193401	0.0159182	1.21
		Land quality	0.6758463**	0.2941635	2.30
Three	Swale	Education	0.0099698	0.0169867	0.59
		Land size	-0.2164395	0.1404752	-1.54
		Land security	0.2685548	0.2305063	1.17
		Slope	-0.3635198***	0.134254	-2.71
		Crop year	0.0151939*	0.0082683	1.84
		Land quality	-0.8544382***	0.1791952	-4.77
Three	Box ridges	Education	-0.0170486	0.0088607	-1.92
		Land size	0.1148647*	0.0512858	2.24
		Land security	-0.2158866*	0.1018389	-2.12
		Slope	0.0346359	0.0546204	0.63
		Crop year	-0.0096622	0.0058761	-1.64
		Land quality	0.4587199***	0.1006991	4.56

Log likelihood = -1 008.8834, LR chi^2 (29) = 663.5568, LR test for IIA = 1: chi^2 (2) = 23.61 (0.000)
*** significant at 1%, ** significant at 5%, * significant at 10%
Source: Calculated from own survey data

Land quality has a positive relationship with choice of contour makers, but a negative relationship with choice of swales, and this is significant at the 5% and 1% levels respectively. Land quality also has a positive and significant relationship with box ridges. This implies that, if farmers perceive that their plots are of good quality in terms of supporting crop production, they are more likely to adopt contour makers and box ridges and less likely to adopt swales. As expected, years of cropping on the same field had a positive relationship with choice of swales at the 10% level of significance. Land size had a positive relationship with choice of box ridges at the 10% level of significance. This means that, as farm size increases, the likelihood of adopting box ridges increases as well. This is consistent with observations by Senkondo *et al.* (1998), who found that farmers with large farm sizes are likely to take the risk of adopting new technology and have a high propensity to experiment with new technologies.

4. Conclusions

The purpose of this study was to identify determinants of adoption of *in situ* and *ex situ* rainwater-harvesting technologies in a rain shadow area of Southern Malawi. The main *ex situ* technology was dams, but farmers mostly adopted *in situ* technologies such as box ridges, contour markers and swales. Both types of technology had an impact on farm income and food security. On average, the farmers treated over 80% of their farms with the *in situ* technologies, because they were easy to operate and maintain, and had a higher water-retention efficiency in the field. The study has therefore demonstrated that perception factors, such as ease of operation and maintenance, have an effect on the intensity of use of rainwater-harvesting technologies on farms. Other important positive factors were security of land tenure, household size, farm size, education and number of years of cropping a plot.

Soil texture and extension played a key role in the choice of both *in situ* and *ex situ* technologies. This result demonstrates the significance of extension advice in terms of the adoption and placement of the technologies in different locations on the farm so that maximum results are achieved. For instance, contour markers and swales were mostly located on gentle to medium slopes, and were found less on lower and higher slopes. Thus, as slope – one of the physical characteristics of farms – decreases, the likelihood of the adoption of swales and contour ridges also decreases on the lower slopes. However, the likelihood of adopting technologies increases when there is a threat of soil erosion on the farm. This means that these interventions should be promoted on more eroded plots on gentler to medium slopes.

The significance of this study is that it has revealed factors affecting both the intensity of use of rainwater-harvesting technologies and modelled dissimilarities among them in terms of placement on the farm. As such, extension services should consider the technologies as a package, so that farmers can implement components of the package in different locations of their farms, depending on the social, economic, institutional and physical factors found on the farm.

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References

Adesina A & Baidu-Forson J, 1995. Farmers' perceptions and adoption of new agricultural technology: Evidence from an analysis in Burkina Faso and Guinea, West Africa. Agricultural Economics 13: 1–9.

Adesina A & Zinnah M, 1993. Technology characteristics, farmers' perceptions and adoption decisions: A tobit model application in Sierra Leone. Agricultural Economics 9: 297–311.

Baidu-Forson, J, 1999. Factors influencing adoption of land-enhancing technology in the Sahel: Lessons from a case study in Niger. Journal of Agricultural Economics 20: 231–9.

Barron J. 2009. Background: The water component of ecosystem services and in human well-being development targets. In Barron J (ed.), Rainwater harvesting: A lifeline for human well-being. Nairobi, Kenya: United Nations Environment Programme and Stockholm Environment Institute.

Chiputwa B, Langyintuo AS & Wall P, 2011. Adoption of conservation agriculture technologies by smallholder farmers in the Shamva District of Zimbabwe: A Tobit application. Paper presented at the 2011 meeting of the Southern Agricultural Economics Association (SAEA), 5–8 February, Corpus Christi, Texas, USA.

Clarke L, 2004. Is water harvesting the future? Daily Times Features, 28 June, p. 21.

Department of Irrigation, 2004. Current initiatives on micro-irrigation and smallholder markets in Malawi. Lilongwe: Ministry of Agriculture, Irrigation and Food Security.

Department of Irrigation, 2011. Draft National Irrigation Policy. Lilongwe: Ministry of Agriculture, Irrigation and Water Development.

He XF, Cao H & Li FM, 2007. Econometric analysis of the determinants of adoption of rainwater harvesting and supplementary irrigation (RHSIT) in the semiarid Loess Plateau of China. Agricultural Water Management 89: 243–50.

Imani Development, 2004. Study on capacity building in support of preparation of economic partnership agreement: Malawi and the European Union. Final draft report. Lilongwe: Government of Malawi.

Kalineza HMM, Mdoe NSY & Mlozi MRS, 1999. Factors influencing adoption of soil conservation technologies in Tanzania: A case of study in Gairo. Morogoro, Tanzania: Sokoine University of Agriculture.

Li F, Cook S, Gabelle GT & Burch Jr WR, 2000. Rainwater harvesting agriculture: An integrated system for water management on rainfed land in China's semiarid areas. Ambio: A Journal of the Human Environment 29(8): 477–83.

Lowenberg-DeBoer J, 2000. Comments on site-specific crop management: Adoption patterns and incentives. Review of Agricultural Economics 22(1): 245–7.

Maddala GS, 1997. Limited dependent and qualitative variables in econometrics. Econometric Society Monograph No. 3. New York: Cambridge University Press.

Maddala GS, 2002. Introduction to econometrics. Third edition. New York: Prentice Hall.

Mangisoni JH, 1999. Land, degradation, profitability and diffusion of erosion control technologies in Malawi. PhD thesis, Department of Applied Economics, University of Minnesota, USA.

Mangisoni JH & Bokosi J, 2004. Socio-economic impact assessment of kalima and napilira bean varieties on smallholder farmers in a smallholder seed security multiplication scheme in Dedza District of Central Malawi. Bunda Journal of Agriculture, Environmental Science and Technology 2: 1–12.

National Statistical Office (NSO), 2012. Integrated household survey 2010-2011, Household socio-economic characteristics report. Zomba, Malawi: National Statistical Office.

Njoloma HM, 2011. An assessment and inventory of investments in rainwater harvesting and small-scale water resources development in Malawi. Final Report to the World Bank. Lilongwe: Rainwater Harvesting Association of Malawi.

Senkondo EMM, Mdoe NSY, Mahoo H & Gowing J, 1998. Factors affecting the adoption of rain water harvesting technologies in Western Pare Lowlands of Tanzania. Tanzania Journal of Agricultural Sciences 1: 81–9.

Shiferaw B, 1997. Peasant agriculture and sustainable land use in Ethiopia: Economic analysis of constraints and incentives for soil conservation. PhD thesis, Department of Economics and Social Sciences, Agricultural University of Norway.

Tesfay NH, 2008. Rainwater harvesting in Ethiopia: Technical and socio-economic potentials and constraints for adoption in Wakro District. MSc thesis, Wageningen University, Wageningen, The Netherlands.

Texas Water Development Board, 1997. Texas guide to rainwater harvesting. Second edition. Austin, Texas: Texas Water Development Board.