IWMI Research Report

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Determinants of Adoption of Rainwater Management Technologies among Farm Households in the Nile River Basin

Gebrehaweria Gebregziabher, Lisa-Maria Rebelo, An Notenbaert, Kebebe Ergano and Yenenesh Abebe

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Front cover photograph shows smallholder agriculture in the Ethiopian Highlands (*photo*: Petterik Wiggers).

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Project

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Collaborators

International Water Management Institute (IWMI)

International Livestock Research Institute (ILRI)

Ethiopian Rainwater Harvesting Association (ERHA)

Amhara Regional Agricultural Research Institute (ARARI), Ethiopia

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Contents

Summary

Agriculture is the main sector of the Ethiopian economy, as is the case in many sub-Saharan African countries. In this region, rainfall distribution is extremely uneven both spatially and temporally. Drought frequently results in crop failure, while high rainfall intensities result in low infiltration and high runoff, causing soil erosion and land degradation, which contribute to low agricultural productivity and high levels of food insecurity. High population growth and cultivation of steep and marginal lands, together with poor land management practices and lack of effective rainwater management strategies, aggravate the situation.

Over the past two decades, the Government of Ethiopia has attempted to address these issues through the large-scale implementation of a range of soil and water conservation measures, including stone terraces, soil bunds and area enclosures. Despite these efforts, adoption of the interventions remains low. Studies from the Ethiopian Highlands show that the adoption of rainwater management technologies is influenced by a variety of factors, including biophysical characteristics such as topography, slope, soil fertility, rainfall amount and variability. However, even when technologies are appropriate to a particular biophysical setting, they may not be implemented, because farmers usually consider a variety of factors when making their decisions to adopt technologies. Thus, gaining an understanding of the factors that influence the adoption of rainwater management technologies is crucial for improved management of land and water resources. In this context, this study has been carried out within the framework of the Nile Basin Development Challenge (NBDC) project of the CGIAR Challenge Program on Water and Food (CPWF), which aims to improve rural livelihoods and their resilience through a landscape approach to rainwater management in the Ethiopian part of the Blue Nile River Basin.

The conceptual framework of this study is based on the premise that farmers are more likely to adopt a combination of promising rainwater management technologies as a coping mechanism against climate variability and agricultural production constraints. For example, multi-purpose trees are likely to complement bunds/terraces, while bunds/terraces are likely to result in increased infiltration and groundwater/surface water recharge, thereby leading to the adoption of shallow/hand-dug wells and, subsequently, orchards and irrigated crops. On the other hand, when farmers adopt area enclosures and/or gully rehabilitation, they usually supplement these with different trees and grasses for animal feed and food production. Similarly, farmers usually invest in river diversion structures for irrigation to produce high-value cash crops. In general, farmers are faced with alternative, but correlated, technologies in their adoption decisions, implying the interdependence of technologies. This is in contrast to much of the previous work carried out on the adoption of rainwater management technologies, which typically examined a single technology without considering the interdependence between technologies. This study contributes to filling this research gap based on evidence from the Blue Nile River Basin. The study assesses the patterns of adoption and the factors that influence farm household adoption of rainwater management technologies, and draws recommendations and policy implications from the results.

The data for this study were obtained from a household survey conducted in seven watersheds in the Ethiopian part of the Blue Nile River Basin in 2011. The sample farm households were selected using a multi-stage stratified random

sampling design. The total sample size was 671, with information from 654 farm households used in the analysis. In addition to descriptive statistics, a multivariate probit model was used to analyze the data.

The regression results showed significant correlation and interdependence between rainwater management technologies. Differences in the estimated coefficients across equations also support the appropriateness of differentiating between technology options. Household demographic characteristics (such as age, gender, marital status and family size in adult equivalent), participation in off-farm activities, migration, ownership of livestock, ownership of land, landholding size per adult equivalent, access to credit centers and markets captured by walking distance, social capital captured by household membership in formal/informal networks, and farm household location captured by the fixed effects (dummies) of the *woredas* (districts) were the main determinants (positive or negative) of adoption of rainwater management technologies.

The main recommendations of the study are as follows: (i) rainwater management interventions should focus not only on the engineering and biophysical performance of conservation measures, but also on the socioeconomic and livelihood benefits; (ii) adoption of rainwater management technologies are interdependent, hence any activity to promote rainwater management technologies need to consider such interdependence. Failure to do so may mask the reality that farmers are typically faced with a set of choices, and will result in poor performance of the technologies; (iii) targeting women groups to address their constraints to actively participate in rural economic activities can have a positive impact on the adoption of rainwater management technologies; (iv) farmers with better experience and information are more likely to adopt and try out new technologies. Identifying these farmers and working with them can help to promote successful and proven technologies; (v) in addition to the socioeconomic and demographic characteristics, it is important to understand the biophysical suitability of technologies instead of promoting blanket recommendations; and (vi) externally driven technical solutions are rarely sustained by farmers unless consideration is given to socioeconomic, cultural and institutional, as well as biophysical and technical factors.

Determinants of Adoption of Rainwater Management Technologies among Farm Households in the Nile River Basin

Gebrehaweria Gebregziabher, Lisa-Maria Rebelo, An Notenbaert, Kebebe Ergano and Yenenesh Abebe

Introduction

Agriculture is the main sector of the Ethiopian economy. It contributes to approximately 42% of the gross domestic product (GDP), generates more than 85% of the foreign exchange earnings and employs over 80% of the population (CSA 2004; MoFED 2010). The Government of Ethiopia is committed to rapid agricultural growth as a means of accelerating economic growth and reducing poverty. Despite impressive achievements over the last three decades, Ethiopia remains one of the poorest countries in the world with over 12 million people being food-insecure. Agricultural productivity is low, dominated by low input-low output rainfed mixed crop-livestock production in the Ethiopian Highlands (Merrey and Gebreselassie 2011). In this region, agricultural productivity is constrained by high climate variability rather than low water availability; rainfall distribution is extremely uneven both spatially and temporally, which has negative implications for the livelihoods of the population (FAO 2005). Drought frequently results in crop failure, while high rainfall intensities result in low infiltration and high runoff, causing soil erosion and land degradation, which contribute to low agricultural productivity and high levels of food insecurity (Lautze et al. 2003; Deressa 2007). High population growth rates and the cultivation of steep and marginal land exacerbates the problem; soil erosion in the cultivated highlands of Ethiopia is estimated to be 42 tonnes/ha, on average (Hurni 1990; Tamene and Vlek 2008).

The use of rainwater management (RWM) interventions, including soil and water conservation (SWC) techniques, is widely accepted as a key strategy to improve agricultural productivity by alleviating growing water shortages, the effects of droughts and worsening soil conditions (Kurukulasuriya and Rosenthal 2003). In the rainfed agroecological landscapes of Ethiopia, the low yield, which is, on average, about 35% of the potential, is typically not due to the lack of water but rather a result of the inefficient management of water, soils and crops (Amede 2012). The gap between actual and attainable yields suggests that there is a large untapped potential for yield increases (Rockström et al. 2010). It has been demonstrated that access to RWM interventions can reduce poverty levels by approximately 22% (Awulachew et al. 2012). These interventions can also provide a buffer against production risks associated with increasing rainfall variability due to climate change (Kato et al. 2009). While various studies have highlighted the potential of RWM interventions to increase agricultural productivity and improve livelihoods in Ethiopia (Pender and Gebremedhin 2007; Kassie et al. 2008; Awulachew et al. 2010), in practice adoption rates of these interventions remain low (Santini et al. 2011).

The Government of Ethiopia along with development agencies has invested substantial resources to promote SWC practices in particular, and a range of interventions including, but not limited to, stone terraces, soil bunds and area enclosures. These have been introduced at a large scale, but with limited success (Zemadim et al. 2011). Since the early 1970s, for example, food for work (FFW) programs have been widely implemented as a means of providing much-needed food aid to rural communities, which are earned by undertaking rural public works. A major component of this has been the construction of soil and water conservation structures, with the intention of preventing or reversing erosion processes (Merrey and Gebreselassie 2011). However, the outcome of these conservation measures was not as expected, and it has been emphasized that interventions should not only focus on the engineering and biophysical performance of conservation measures but also on the socioeconomic and livelihood benefits (Zemadim et al. 2011). Studies from the Ethiopian Highlands show that the adoption of RWM technologies are influenced by a variety of factors, including biophysical characteristics such as topography, slope, soil fertility, rainfall amount and rainfall variability (Deressa et al. 2009). Experience also shows that even when technologies are appropriate for the biophysical setting, they are not always adopted (Guerin 1999; Amsalu and Graaff 2007) because farmers consider a variety of factors when making a decision to adopt a particular intervention (McDonald and Brown 2000; Soule et al. 2000). In addition, studies have found that farmers' recognition of the problem (e.g., soil erosion, low agricultural productivity) and awareness of the potential solutions are necessary, but not sufficient conditions for the adoption and continued use of SWC technologies (Merrey and Gebreselassie 2011). Externally driven technical solutions are rarely sustained by farmers unless consideration is given to socioeconomic, cultural and institutional as well as biophysical and technical factors (McDonald and Brown 2000; Merrey and Gebreselassie 2011). An empirical study from the Nile Basin (Deressa et al. 2009) demonstrated that, among others, the level of education, gender, age, farm and non-farm income, wealth of the household, access to extension and credit, information on climate, farmer-to-farmer extension and number of relatives (as a proxy of social capital) influence farmers' adoption of RWM technologies. Hence, one way to improve productivity and build climate-resilient livelihoods in the Ethiopian Highlands is to target promising technologies to a particular (biophysical and socioeconomic) environment. Santini et al. (2011), for example, highlighted the need for new models of planning for RWM investments by recognizing the diversity and complexity of the country contexts, and by tailoring the interventions to suit the priorities and livelihood strategies of the rural population. This helps to overcome the limited success and impact of practices that are often adopted using 'blanket' approaches (ILRI and IWMI 2010). In addition, a package of technologies should be considered rather than individual interventions.

However, there is no agreement on the factors that encourage or discourage adoption of specific technologies and practices (which can be farm- and/or technology-specific), and a better understanding of these factors is needed. Furthermore, relatively little empirical work has been undertaken to examine the factors that affect the adoption of RWM technologies at the watershed level, or as a 'package' or combination of technologies. Most of the previous research that has been conducted has focused on the adoption of individual technologies over a large (country or regional) scale, while farmers typically adopt multiple RWM technologies that deal with their overlapping constraints and are suitable to specific landscapes and the position within the landscape. Kato et al. (2009), for example, highlighted that the effectiveness of various SWC technologies in Ethiopia depend on whether they are used independently or as a package. As the suitability of RWM technologies may depend on the position within a landscape, interventions implemented in the upper slopes are likely to be different from those implemented in the lower slopes. Under such a scenario, analyses which do not take into account landscape or watershed variability may underestimate or over-estimate the influence of factors affecting the adoption of technologies.

As limited rigorous empirical work has been carried out on the economic factors that influence the adoption of particular technologies (Kassie et al. 2008), the objective of this study is to understand the factors that influence adoption or dis-adoption of a particular RWM technology and combinations of technologies in the Ethiopian Highlands. The outcome of this study contributes to the growing evidence base for the adoption of RWM technologies as a strategy for sustainable agriculture and climate-resilient livelihoods.

Study Area and Data

This study has been carried out within the framework of the Nile Basin Development Challenge (NBDC) project, which aims to improve livelihoods of the rural population and build their resilience to climate change through a landscape approach to rainwater management in the Ethiopian part of the Blue Nile River Basin. Within this region, three landscapes were identified and selected for this study – Jeldu, Diga and Fogera. These landscapes were different in their state of development, agroecology and livelihood systems, and there were opportunities for the implementation of rainwater management strategies. Action research sites have been selected within these study landscapes, providing a nested set of sites for learning and research. The sample watersheds for the current study include these three NBDC research action sites (Meja in Jeldu, Dapo in Diga and Mizewa in Fogera) along with four new sites (Boke, Laku, Zefe and Maksegnit) which are also located within the Blue Nile River Basin (Figure 1).

The four new sites were selected by the national partners, Oromia Agricultural Research Institute (OARI) and Amhara Regional Agricultural Research Institute (ARARI), for the purpose of this study and to fit in with the NBDC definition of a landscape. The criteria used to select the new watersheds include the presence of RWM interventions, and size and slope of the watershed. Similar to the NBDC sites, the four new watersheds should be relatively small and managed by one or two communities. The biophysical description of the study sites is presented in Table 1.

Cross-sectional data have been collected from 671 randomly selected sample households (see Table 2) for the purpose of this study.

A multi-stage stratified random sampling procedure was used to select the sample households. In the first stage, a list of households from each *kebele* (community) within the watershed was used to stratify them by location of landscape. Following this, households in the selected watersheds were stratified into female- and male-headed households, and according to adoption status (i.e., adopter and non-adopter), in order to generate a reasonable proportion of both these household categories for a counterfactual analysis. Finally, proportional random sampling was employed to identify 671 sample households. The adoption rate of RWM technologies disaggregated by gender is presented in Appendix, Table A1. Following data collection, it became apparent that 17 households from the Meja watershed had been wrongly surveyed. Thus, by excluding these households, only 654 of the sample households were considered in the analysis. For data collection, a structured questionnaire that comprised a set of household and community level information was used.

TABLE 1. Biophysical characteristics of the sample watersheds.

Woreda	Sample watershed	Nearest rainfall and temperature station	Mean Aridity Index (AI)	Erosion (rate/tonnes/ha/year)	Average travel time to nearest town in hours	Rainfall variability coefficient of variance (CV)	Temperature	Soil type*
Gondar Zuria	Maksegnit	Gondar Zuria	0.68* Humid	20.82* High	3*	0.298	27	Chromic Luvisols, Eutric Leptosols and Eutric Vertisols
Fogera	Mizewa	Worota/Addis Zemen	0.66* Humid	1.78* Low	4*	0.348 Eutric Fluvisols	29	Haplic Luvisols and
Farta	Zefe	Debre Tabor	0.81** Humid	28.66** High	4**	0.316	22	Chromic Luvisols
Diga	Dapo	Nekemte	0.96* Humid	4.45* Low	4*	0.305	24	Haplic Alisols
Horo	Laku	Shambu	1.03** Humid	13.14** Moderate	5**	0.328	22	Haplic Alisols
Jeldu	Meja	Ambo	0.89* Humid	1.94* Low	2*	0.854	23	Haplic Alisols
Ambo	Boke/Gorosole	Tikur Inchini	0.72** Humid	29.36** High	5**	0.228	23	Chromic Luvisols
	Source		Zomer et al. 2007, 2008; Spinoni et al. 2013 Consortium for Spatial Information (CGIAR-CSI) Global Aridity and PET Database (Available at http: //www.cgiar-csi.org)	Haileslassie et al. 2005; Shiferaw 2011	Global Agriculture and Food Security Program (GAFSP) Ethiopia – Average travel time to nearest town over 20K (hours) (2000) (Available at http: //maps.worldbank. org/overlays/7406)	NMA 2007; National Meteorology Agency (NMA), Ethiopia, dataset and information resources (http://www. ethiomet.gov.et/ data_access/ information)		MoWE 1998a

Notes: Soil erosion severity classes: 0-10, 10-20, 20-30, 30-45, 45-60, 60-80 and > 80 classified as Low, Moderate, High, Very high, Severe, Very severe and Extremely severe, respectively.

Aridity Index classes: < 0.05, 0.05-0.2, 0.2-0.5, 0.5-0.65 and > 0.65 classified as Hyper-arid, Arid, Semi-arid, Dry Sub-humid and Humid, respectively.

* Watershed scale

** *Woreda* scale

FIGURE 1. Location of selected sample watersheds.

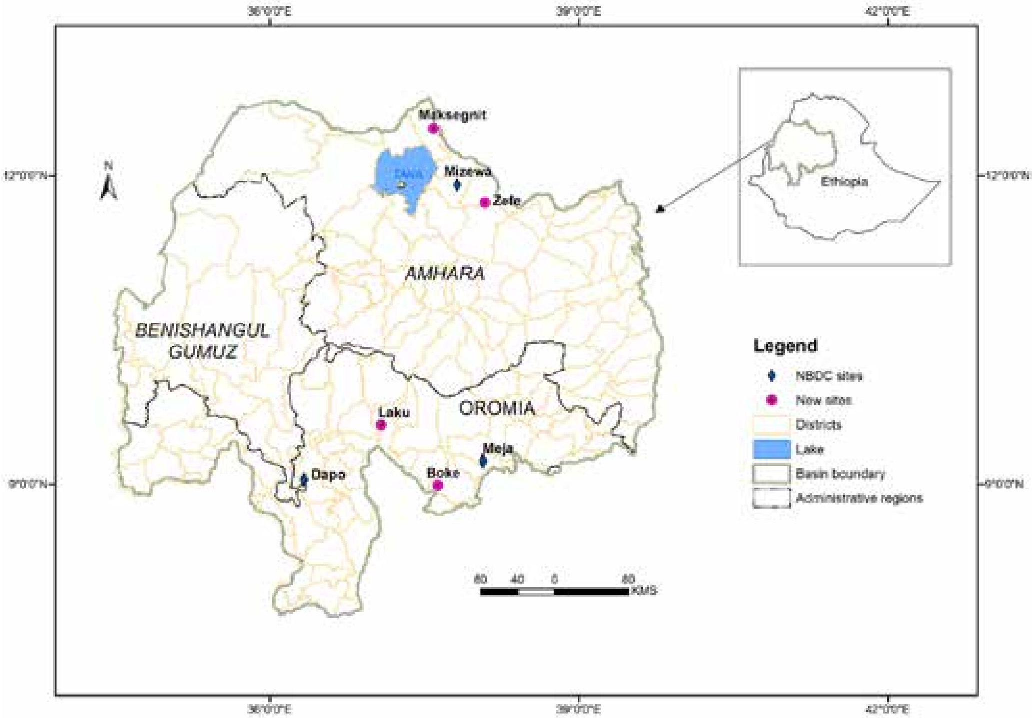


TABLE 2. Watersheds surveyed and the number of randomly selected sample households.

Region	*Woreda*/District	Watershed	Site	Number of sample households	Data collected by
Oromia	Jeldu	Meja	NBDC	120	ERHA
	Guder	Boke	New	90	OARI
	Shambu	Laku	New	90	OARI
	Diga	Dapo	NBDC	90	OARI
Amhara	Farta	Zefe	New	90	ARARI
	Fogera	Mizewa	NBDC	101	ARARI
	Gondar Zuria	Gumera/Maksegnit	New	90	ARARI
Total				671	

Methodology

The methodological framework is based on the premise that farmers are more likely to adopt a combination of rainwater management technologies, which may be adopted simultaneously and/or sequentially as a complement or supplement to each other.

For example, multi-purpose trees are likely to complement bunds/terraces, while bunds/terraces are likely to result in increased infiltration and groundwater/surface water recharge, thereby leading to the adoption of shallow/hand-dug wells and, subsequently, orchards and irrigated crops. On the other hand, when farmers adopt area enclosures and/or gully rehabilitation, they usually supplement these with different trees and grasses for animal feed and food production. Similarly, farmers usually invest in river diversion structures for irrigation to produce high-value cash crops. In general, farmers are faced with alternative, but correlated, technologies in their adoption decisions, which implies the interdependence of technologies. Furthermore, the choice of technologies selected may be partly dependent on earlier experiences (Kassie et al. 2012). Various empirical studies (Moyo and Veeman 2004; Marenya and Barrett 2007; Nhemachena and Hassan 2007; Yu et al. 2008; Kassie et al. 2009) argued that farmers usually consider a set of possible technologies and select the single one that they assume will have the best results; hence, the adoption decision is inherently multivariate. However, most previous studies of technology adoption (such as rainwater management and conservation technologies) assume a single technology without considering the possible correlation/interdependence between different technologies (Yu et al. 2008), thereby masking the reality that decision makers are often faced by a set of choices. In general, when technologies are correlated, univariate modeling excludes useful information contained in the interdependence and adoption decision analysis. A single technology approach may, therefore, underestimate or over-estimate the influence of factors on the adoption decision. In general, univariate models ignore the potential correlation among unobserved disturbances in the adoption equations as well as the relationships between the adoption of different rainwater management technologies, because farmers may consider some combination of technologies as complementary and/or competing. Failure to capture such interdependence will lead to biased and inaccurate estimates.

In this context, we employ a multivariate probit model (MVP) (Kassie et al. 2012; Cappellari and Jenkins 2003) as shown in Equations (1) and (2).

$$Y^*_{ht} = \beta_t X'_{ht} + \varepsilon_{ht},\ t = 1,....m \text{ and} \tag{1}$$

$$Y^*_{ht} = 1 \text{ if } Y^*_{ht} > 0 \text{ and } 0 \text{ otherwise} \tag{2}$$

where: $T = 1,...m$ represents the choices of rainwater management technologies. The assumption is that h^{th} farm household has a latent variable Y^*_{ht} that captures the choices associated with the T^{th} rainwater management technology.

The estimation is based on the observed binary discrete variables Y^*_{ht} that indicate whether or not h^{th} farm household has adopted a particular rainwater management technology (denoted by 1 for adoption and zero for non-adoption). The status of adoption is assumed to be influenced by observed characteristics (X_{ht}), including household characteristics, access to services, markets, social capital (captured by household's membership in formal and/or informal social groups), and biophysical characteristics captured by *woreda*/district dummies. The unobserved characteristics are captured by the error term denoted by ε_{ht}, while β_t is a parameter to be estimated.

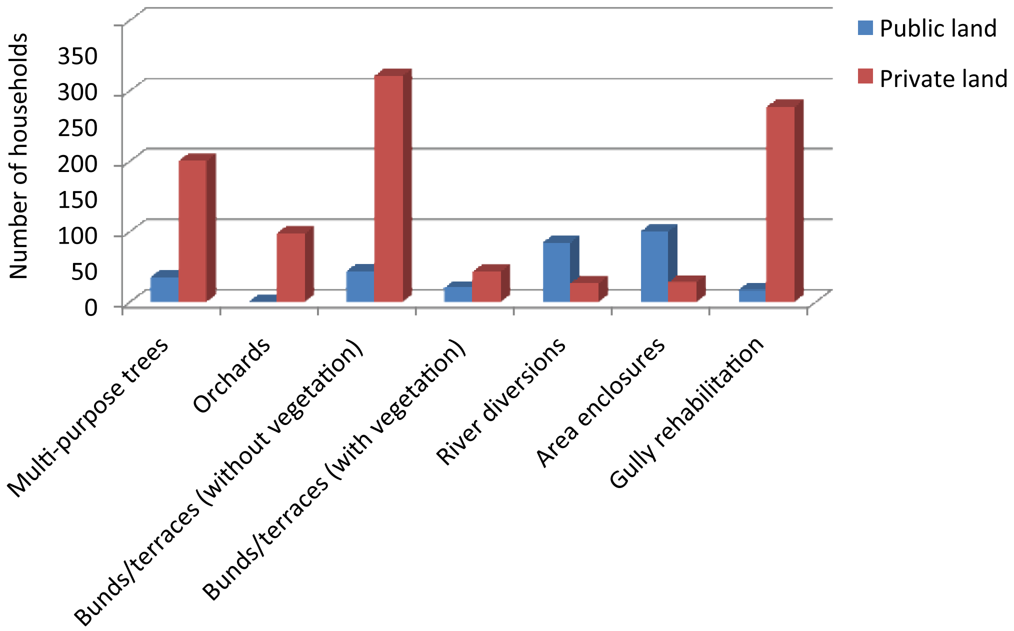
In line with this, we assume that rainwater management technologies considered in this study are interdependent, implying that the adoption of one technology is likely to influence (positively or negatively) the adoption of another technology, hence the error terms (ε_{ht}, $t = 1,...,m$) in Equation (1) are distributed as multivariate with zero mean and variance 1, where $\varepsilon_{ht} \approx MVN(0,V)$. The value of variance (V) is, therefore, normalized to unity on the diagonal and correlations as off-diagonal elements in Equation (3). The non-zero value of the off-diagonal elements allow for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative rainwater management technologies (Kassie et al. 2012). The covariance matrix V is given in Equation (3):

$$V = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \cdots & \rho_{1m} \\ \rho_{21} & 1 & \rho_{23} & \cdots & \rho_{2m} \\ \rho_{31} & \rho_{33} & 1 & \cdots & \rho_{3m} \\ \vdots & \vdots & \vdots & 1 & \vdots \\ \rho_{m1} & \rho_{m2} & \rho_{m3} & & 1 \end{bmatrix} \quad (3)$$

In general, the multivariate probit model is a generalization of the probit model that is used to estimate numerous correlated binary outcomes jointly, where the source of correlation can be complementarity (positive correlation) and substitutability (negative correlation) between different technologies (Belderbos et al. 2004).

Although nine rainwater management technologies were initially considered, it was clear from the survey data that adoption rates of shallow wells and ponds were low and insufficient to undertake further statistical analysis. Moreover, as the estimation of the multivariate probit model was cumbersome to converge, bunds/terraces with vegetation and without vegetation were merged as one technology. Finally, we reviewed whether the technologies were adopted on private or public (communal) land and the result showed that river diversions and area enclosures were adopted on public lands (Figure 2), as collective action. Since the analysis is based on household-level data, both river diversions and area enclosures were excluded from the analysis. Hence, only four rainwater management technologies (multi-purpose trees, orchards, bunds/terraces and gully rehabilitation) were considered in the analysis.

FIGURE 2. Adoption of rainwater management technologies and ownership of land.



Independent Variables and Hypotheses

The explanatory variables considered in the analysis and their expected effects on the adoption of rainwater management technologies are discussed below.

Household characteristics: In this regard, we considered different household characteristics and family member composition as a proxy for the human capital of the households. For example, the level of education, age and gender of the family members, and family size are important indicators of the available human capital, which has an influence on the adoption of technologies. Households with more educated members are likely to have better access to information, and are more aware about the merits and demerits of the technologies. They are also able to interpret new information to make knowledge-based decisions in favor of appropriate/suitable technologies. On the other hand, households with more educated members may be less likely to invest in labor-intensive technologies and practices, because they are more likely to earn higher returns from their labor and capital investment through other activities (Kassie et al. 2012; Pender and Gebremedhin 2007). The age of the members of the household may imply farming experience and the ability to respond to unforeseen events/shocks. Older household heads may have an accumulation of capital and respect in their community, implying greater social capital. On the other hand, age can be associated with loss of energy and short planning horizons, and the reluctance towards new technologies due to risk aversion behavior.

Gender is an important factor in terms of access to resources. The general argument is that women have less access to important resources and services, such as land, labor, credit and education, and are generally discriminated against in terms of access to external inputs and information (De Groote and Coulibaly 1998; Quisumbing et al. 1995). In sub-Saharan Africa, there are gender-specific constraints that women face, such as less education, inadequate access to land, and production assets and livestock ownership. These constraints will clearly have a direct effect on technology adoption (including rainwater management technologies), where women are usually less likely to adopt these technologies as they are resource-demanding and labor-intensive (Ndiritu et al. 2011).

Capital ownership: This variable is captured by the number of livestock (Total Livestock Units [TLU]), farm size per adult equivalent (a dummy variable that captures whether or not a farm household owns the land) and the value of durable household assets. The assumption is that households that own more capital are wealthier and more likely to take risks associated with the adoption of new technologies. Moreover, such households are less constrained financially and are able to purchase inputs. Household expenditure is also considered as a proxy for income level. Hence, the expected effect of capital on the adoption of rainwater management technologies is positive. However, since households with relatively large landholdings may be able to diversify their crops and income sources, they may be less susceptible to risks and shocks; as such, they may be less interested in investing in rainwater management technologies as a coping mechanism.

Off-farm activity: Economic incentives play an important role in the adoption of rainwater management technologies. Households' access to off-farm employment and alternative sources of income are likely to influence the adoption of rainwater management technologies in different ways. For example, those who have alternative sources of income are better able to adopt and invest in these technologies. On the other hand, participation in off-farm income-generating activities is likely to divert labor from on-farm activities and working on rainwater management technologies, both as a private investment and as collective action. The findings of Deressa et al. (2009) supported this hypothesis. Off-farm activity is captured by the participation of household members in the FFW program and/or whether any member of a household had migrated. Both these variables are defined as dummy variables (a value of 1 for participation and zero otherwise).

Access to markets, extension, credit and inputs: The walking distance (in minutes) was used as a proxy of access to markets, extension and input supply centers. Access to credit was captured by the household response when asked whether they had requested for credit and the actual amount of the loan they received in the previous year. Access to markets can influence the use of various inputs as well as access to information and support services. For example, Deressa et al. (2009) revealed that access to credit has a significant positive impact on the likelihood of using soil conservation techniques, changing planting dates and using irrigation in the Blue Nile River Basin. Therefore, the hypothesis is that the longer the walking distance to markets and other service centers, the less likely it is that households will adopt a particular rainwater harvesting technology.

Social capital: This is represented by variables such as the household membership in informal institutions (such as Equib and Edir)[1]. In Ethiopia, it is common for rural communities to form informal groups for labor sharing, and saving and risk-sharing mechanisms. This can take place in the form of friendship or kinship networks, implying that households with a large number of relatives and wider networks are likely to be more resilient to risk and have fewer credit constraints; they are more likely to adopt technologies because they are in a better position to take risks (Fafchamps and Gubert 2007). With limited information and imperfect markets, social networks can facilitate the exchange of information, enabling farmers to access inputs and overcome credit constraints. Social networks also reduce transaction costs and increase farmers' bargaining power, helping them to earn higher returns when marketing their products, which in turn can affect technology adoption (Lee 2005; Pender and Gebremedhin 2007; Wollni et al. 2010). Moreover, farmers who have limited contacts with extension agents can be informed about the methods and benefits of new technologies from their networks, as they share information and learn from each other. On the other hand, having more relatives may reduce incentives for hard work and induce inefficiency, such that farmers may exert less effort to invest in technologies (Kassie et al. 2012). The expected effect of the social capital coefficient is, therefore, ambiguous prior to empirical testing.

Biophysical characteristics: Various rainwater management technologies can be used as a coping mechanism in areas with low rainfall and moisture stress, while others are more suited to areas with high rainfall. Unfavorable rainfall amounts, such as too little rainfall, may encourage farmers to adopt soil and water conservation practices. On the other hand, the high rainfall intensities that result in high runoff can augment soil erosion leading to nutrient depletion. It can also increase waterlogging (Kassie et al. 2010), which may negatively influence the likelihood of adoption of soil and water conservation practices. Hence, farm households may adopt certain rainwater management technologies (e.g., bunds/terraces) to reduce exposure to rainfall hazards by increasing soil moisture, reducing soil loss from erosion and flooding, and diversifying cropping patterns.

In the Blue Nile River Basin, the topography follows a gradient from the flat lowlands in the West to mountainous areas in the East. While it is acknowledged that topographical and soil characteristics will affect the suitability of rainwater management technologies (due to the lack of site-specific biophysical data), we considered district/*woreda* dummies, for example, equal to 1 if the *woreda* is Guder and zero otherwise, assuming that such dummy variables can capture unobserved biophysical properties of the sites.

[1] Equib is an informal saving group. Edir is an informal group formed by members of the community, mainly for self-support.

Results and Discussion

Descriptive Results

The number of households that have adopted rainwater management technologies varies across the watershed (Table 3). Bunds/terraces followed by gully rehabilitation, multi-purpose trees, area enclosures, river diversions, orchards, shallow/hand-dug wells and ponds are the most adopted technologies across the study sites. Furthermore, Zefe, Gumera/Maksegnit and Mizewa watersheds (all in the Amhara region) were found to have the highest rates of adoption of rainwater management technologies.

Zemadim et al. (2011) indicated that there are successful situations of RWM programs as part of sustainable land management (SLM) to increase in-situ water availability and increase aquifer recharge in the Blue Nile River Basin. On the other hand, despite massive investments in ponds, the adoption rate is minimal and possibly due to its low rate of success. This is consistent with findings of a study carried out by Arba Minch University (AMU 2009), which stated that most of the 40,000 rainwater harvesting ponds were individually owned and mainly used for supplementary irrigation. Most of the ponds constructed between 2003 and 2008 in the Amhara and Tigray regions of Ethiopia have, however, failed, which was mainly due to faulty design, wrong location of ponds and lack of monitoring after their construction. This all leads to farmers' lack of confidence to invest in the technology.

In many parts of the Ethiopian Highlands, farmers have been practicing rainwater management technologies, such as bunds/terraces, to preserve the topsoil and ensure sustainable cultivation of crops for their sustenance. Slope is a major factor in determining whether bunds or terraces should be constructed for soil conservation in a given place. Terraces are usually found on medium to steep slopes and can be created by moving soil from one place to another on the slope, which involves a lot of work. Data in Table 3 show that bunds/terraces were practiced by about 70% of the sample households.

Multi-purpose trees are part of the RWM strategies. Farmers adopt this technology for soil and water conservation and for obtaining fuelwood. Despite the promotion of multi-purpose fodder trees for livestock feed and soil improvement by many organizations, the number of farmers practicing this technology remains low (Mekoya 2008). For instance, about 32% of the total sample households adopted multi-purpose trees, while about 54%, 47% and 46% of sample households in Boke, Laku and Dapo watersheds, respectively, adopted this technology. Area enclosures and gully rehabilitation were adopted by about 18% of the total sample households, but these were mostly adopted by watersheds

TABLE 3. Number of households that adopted rainwater management technologies in watersheds.

RWM technology	Watersheds							Total
	Meja	Zefe	Maksegnit	Boke	Dapo	Laku	Mizewa	
Multi-purpose trees	22	18	16	53	52	45	15	221
Orchards	1	25	7	2	31	13	10	89
Bunds/terraces	13	78	78	67	76	70	86	468
Shallow/hand-dug wells	0	9	1	2	1	3	1	17
Ponds	0	3	2	1	0	2	5	13
River diversions	9	13	12	16	7	12	28	97
Area enclosures	1	41	43	7	1	2	19	114
Gully rehabilitation	54	74	77	36	18	36	57	352
Total	100	261	236	184	186	183	221	1,371

in Amhara rather than Oromia. On the other hand, about 34% of sample households in Dapo watershed have practiced orchards, while the least number of adopters of this technology were from Meja watershed (see Table 3). Rainwater management technologies are interdependent and correlated, and hence farmers are more likely to adopt a combination of these technologies as complements or substitutes. Among the sample households, for example, 55, 173, 109, 82, 48, and 277 adopted a combination of multi-purpose trees and orchards, multi-purpose trees and bunds/terraces, multi-purpose trees and gully rehabilitation, orchards and bunds/terraces, orchards and gully rehabilitation, and bunds/terraces and gully rehabilitation, respectively, where most of them were positively correlated (Appendix, Table A4).

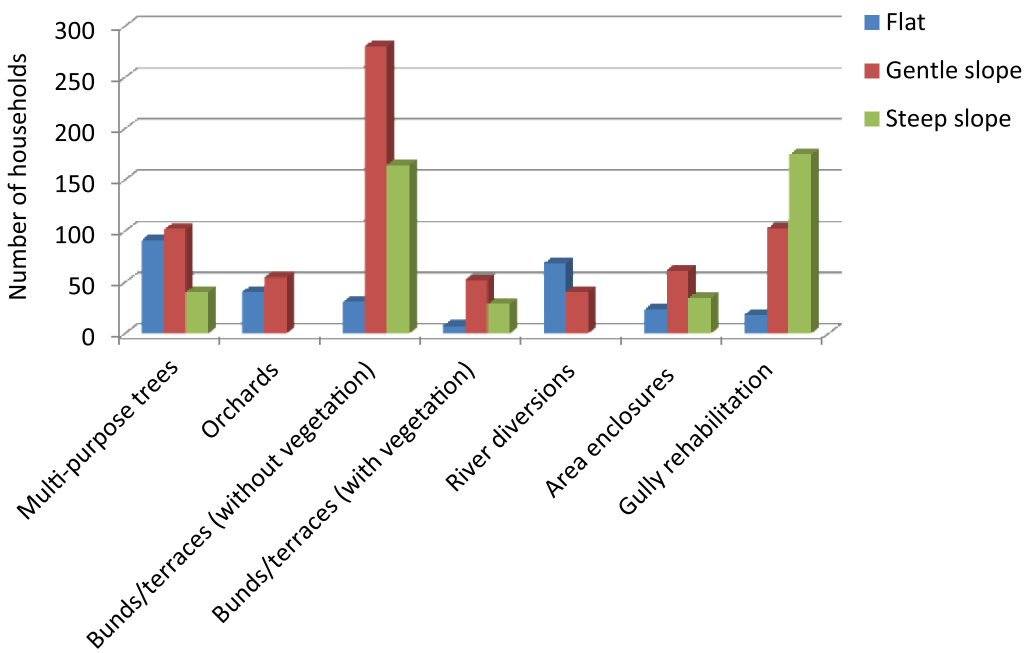
The suitability of rainwater management technologies is likely to be influenced by landscape. Figure 3 shows that most households' adoption of multi-purpose trees, orchards, bunds/terraces and area enclosures were on lands with a gentle slope, while river diversions and gully rehabilitation were suited to lands with a flat and steep slope, respectively.

The level of land degradation is also more likely to affect a household's decision to adopt a rainwater management technology. Based on the responses from our sample households, we observed that, except for bunds/terraces, most of the other rainwater management technologies were adopted on degraded lands, which was probably because these technologies were used as ex-post land rehabilitation and resource conservation mechanisms (Figure 4).

In addition to land degradation, land-use type is also likely to influence the suitability and decision of farm households to adopt a RWM technology. Multi-purpose trees have a higher rate of adoption on croplands and grasslands (Figure 5). Similarly, orchards and bunds/terraces were adopted on both land-use types, although the rate of adoption seems to favor croplands. Gully rehabilitation has been adopted more on grasslands. Finally, the survey data indicate that river diversions and area enclosures are more suited to croplands and grasslands, respectively. This result is not unexpected, because river diversions are used for irrigation and area enclosures are used for land conservation and natural resource regeneration.

Table 4 presents the definition and summary statistics of both dependent and independent variables used in this analysis. Accordingly, about 35% of sample households

FIGURE 3. Adoption of rainwater management technologies according to landscape.



adopted multi-purpose trees, while about 15%, 72% and 56% of the sample households adopted orchards, bunds/terraces and gully rehabilitation, respectively.

FIGURE 4. The effects of land degradation on the adoption of rainwater management technologies.

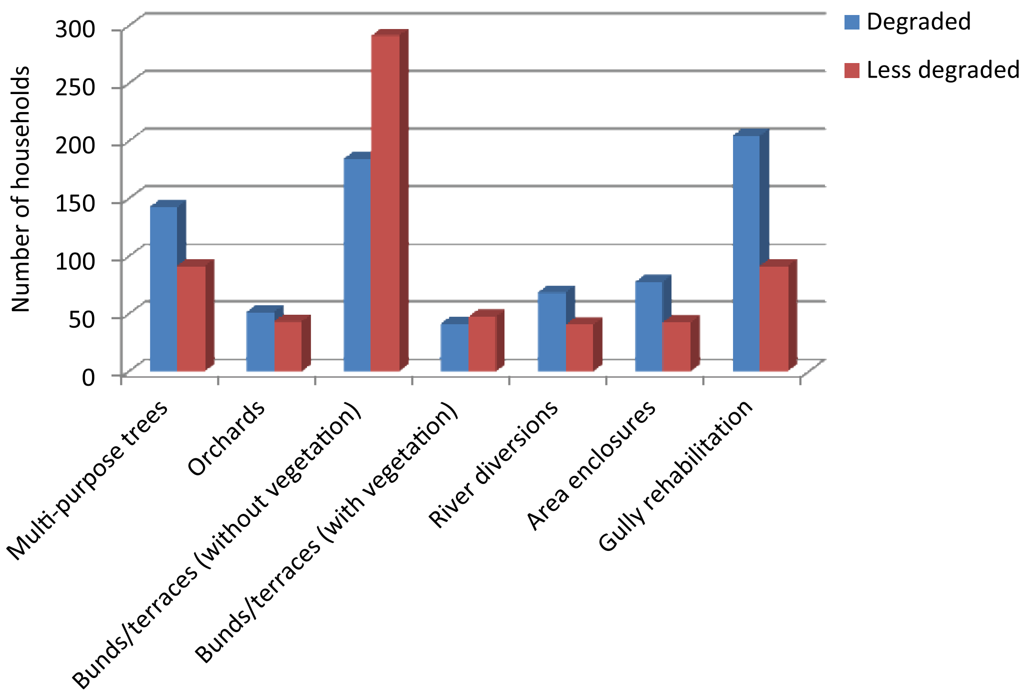


FIGURE 5. Adoption of rainwater management technologies according to land-use type.

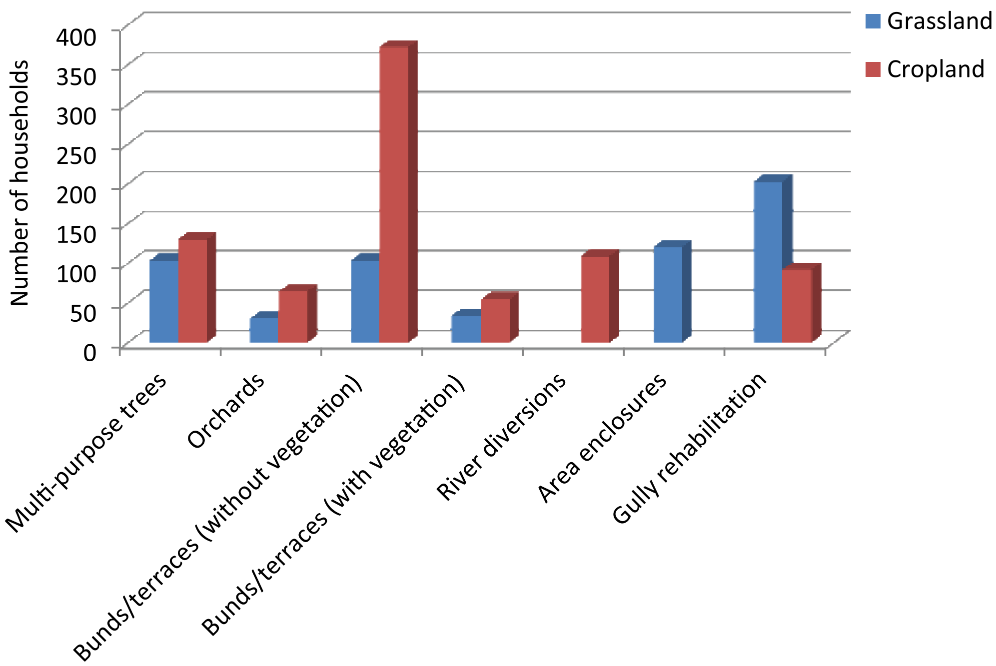


TABLE 4. Definition and descriptive statistics of dependent and independent variables.

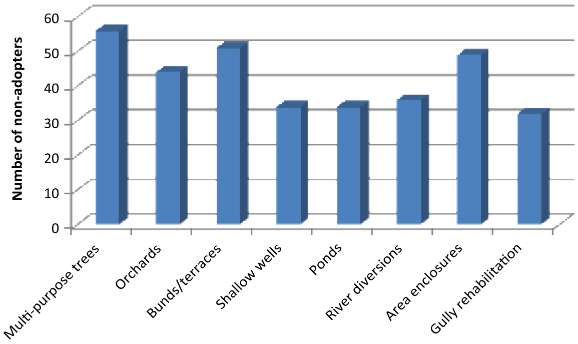
Variable description		
Dependent variables	Frequency	
	Yes	No
Multi-purpose trees (1 = yes, 0 = no)	221	433
Orchards (1 = yes, 0 = no)	89	565
Bunds/terraces (1 = yes, 0 = no)	468	186
Gully rehabilitation (1 = yes, 0 = no)	352	302
Independent variables	**Mean**	**Std. Dev.**
Age of household head (years)	46.996	15.342
Gender of household head (1 = male, 0 = female)	0.846	0.361
Farming experience (years)	27.121	15.705
Marital status of household head (1 = married, 0 = single/separated/divorced)	0.838	0.369
Family size in adult equivalent (number)	4.684	2.073
Household head is educated or at least can read and write (1 = yes, 0 = no)	0.200	0.400
Number of household members with elementary (1-8) education level (number)	1.979	1.618
Number of household members with high school and above (>= 9) education level (number)	0.787	1.216
At least one household member participates in off-farm activities (1 = yes, 0 = no)	0.276	0.447
At least one household member has migrated (1 = yes, 0 = no)	0.133	0.339
Total household expenditure during the previous year (ETB)	2,939	14,539
Household’s livestock holding in TLU (number)	5.234	4.612
Household’s own land (1 = yes, 0 = no)	1.002	0.723
Landholding per adult equivalent (ha)	0.428	0.399
One-way walking distance to all-weather road (minutes)	29.241	29.596
One-way walking distance to *woreda* center (minutes)	47.076	36.354
One-way walking distance to farmer training center (minutes)	35.408	27.626
One-way walking distance to credit center (minutes)	47.375	39.422
Household participates in Debo (1 = yes, 0 = no)	0.890	0.313
Household participates in Equib (1 = yes, 0 = no)	0.125	0.331
Household participates in Edir (1 = yes, 0 = no)	0.925	0.285
Household member participates in women’s association (1 = yes, 0 = no)	0.201	0.401
Jeldu District (*woreda*) (1 = yes, 0 = no) ***control woreda***	0.180	0.385
Guder District (*woreda*) (1 = yes, 0 = no)	0.320	0.467
Horo (Shambu) District (*woreda*) (1 = yes, 0 = no)	0.314	0.465
Diga District (*woreda*) (1 = yes, 0 = no)	0.314	0.465
Farta District (*woreda*) (1 = yes, 0 = no)	0.314	0.465
Gondar Zuria District (*woreda*) (1 = yes, 0 = no)	0.310	0.463
Fogera District (*woreda*) (1 = yes, 0 = no)	0.328	0.470

Notes: Debo – a traditional labor sharing system; Std. Dev. = Standard deviation.

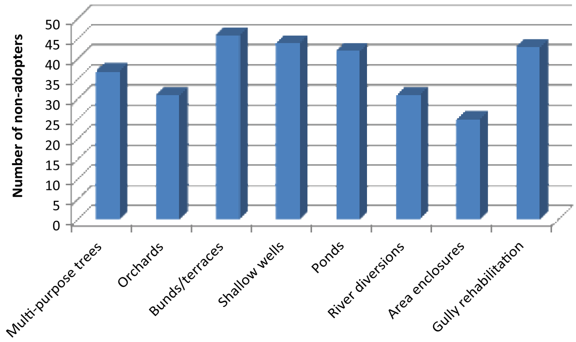
These results are based on the responses of farm households that have already adopted some of the technologies, and hence do not capture the perceptions of non-adopters and their limitations to invest in and adopt the technologies. In line with this, Figure 6 presents the perceptions of non-adopters and highlight the constraints that impede farmers' investment in rainwater management technologies.

FIGURE 6. Number of non-adopters who consider factors as constraints for not adopting rainwater management technologies.

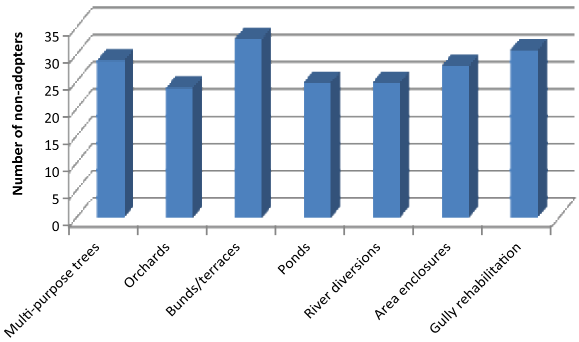
(a) Shortage of land.



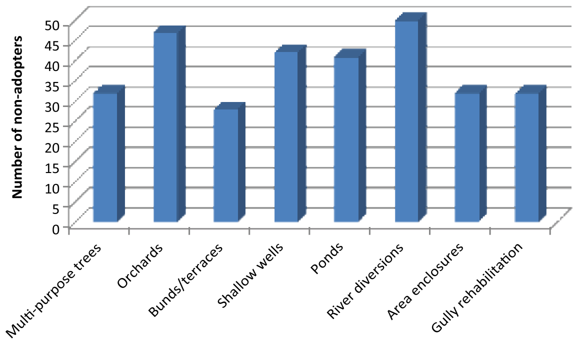
(b) Lack of labor.



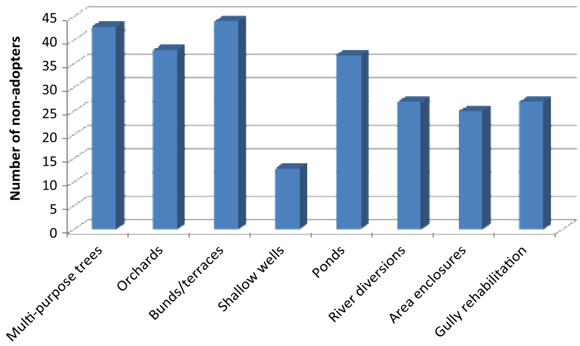
(c) Lack of cooperation with neighborhood.



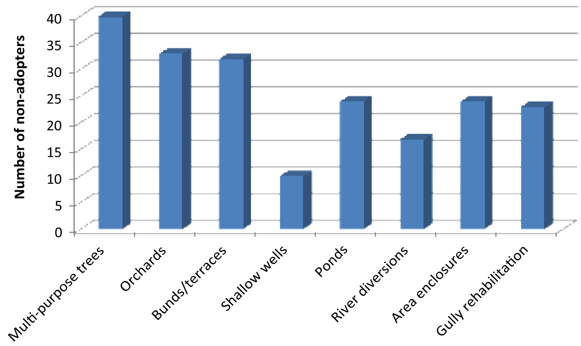
(d) Technology is not suitable on farmer's land.



(e) Lack of capital/credit.



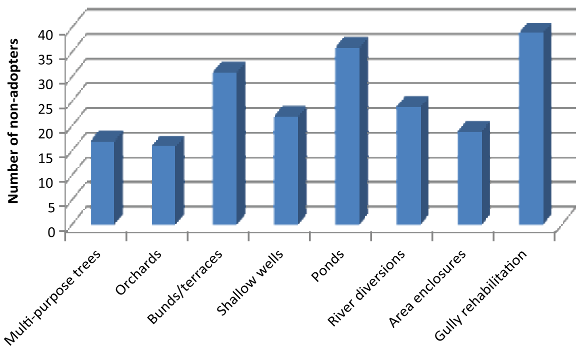
(f) Lack of proper technical advise.



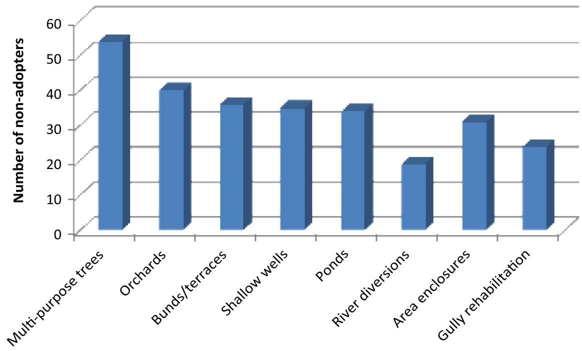
(Continued)

FIGURE 6. Number of non-adopters who consider factors as constraints for not adopting rainwater management technologies (Continued).

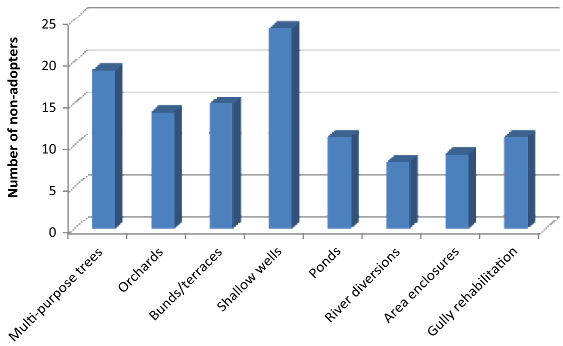
(g) It is labor- and time-intensive (tiresome).



(h) Lack of awareness about the technology.



(i) Limited access to markets.



Regression Results

Parameter estimates from the multivariate probit model are presented in Table 5. The regression results revealed that the determinants of adoption of rainwater management technologies can be broadly classified into household and socioeconomic characteristics, access to markets and services, social capital and district-specific characteristics.

Coefficients that capture correlation between the technologies are presented in Table 6. These essentially indicate pair-wise correlations between the error terms in the system of equations of the multivariate probit model. Results show that, with the exception of orchards and gully rehabilitation, all the other rainwater management technologies are positively and significantly correlated, which supports the hypothesis. The error terms in the rainwater management technology adoption equations are not independent of each other, and hence a multivariate probit approach is appropriate in this case. Similarly, the likelihood ratio test [$\chi^2(6) = 36.324$ and probability $> \chi^2 = 0.000$] indicates a significant joint correlation between the technologies, and supports the estimation of the multivariate probit model as opposed to a separate univariate probit model.

Furthermore, the positive and significant correlation coefficients of the error terms indicate that there is complementarity (positive correlation) between different rainwater management technologies being used by farmers, and supports the assumption of interdependence between the different rainwater management technology options. Differences in the estimated coefficients across equations also support the appropriateness of differentiating between technology options.

TABLE 5. Results of the multivariate probit model.

Independent variables	Technologies (dependent variables)							
	Multi-purpose trees		Orchards		Bunds/terraces		Gully rehabilitation	
	Coefficient		Coefficient		Coefficient		Coefficient	
Human capital								
Age of household head (years)	-0.011***	(-0.004)	-0.018***	(-0.006)	-0.013***	(-0.005)	-0.0122***	(-0.004)
Gender of household head (1 = male)	0.760***	(-0.221)	0.379	(-0.312)	0.159	(-0.233)	0.056	(-0.214)
Marital status of household head (1 = married)	-0.555***	(-0.202)	-0.242	(-0.291)	0.202	(-0.214)	-0.0725	(-0.211)
Family size in adult equivalent	0.147***	(-0.043)	0.213***	(-0.054)	0.024	(-0.052)	0.040	(-0.044)
Household head is educated (1 = yes)	0.175	(-0.154)	-0.016	(-0.185)	0.122	(-0.169)	0.0306	(-0.150)
Number of household members with elementary (1-8) education level	-0.032	(-0.046)	-0.001	(-0.059)	0.035	(-0.054)	0.036	(-0.045)
Number of household members with high school and above (>= 9) education level	-0.018	(-0.058)	-0.014	(-0.075)	-0.080	(-0.066)	-0.012	(-0.058)
Total household expenditure during the previous year	0.001	(0.001)	0.001	(0.001)	0.001	(-0.001)	0.001	(0.001)
Physical capital								
Livestock holding in TLU	0.015	(-0.015)	0.031	(-0.018)	0.050***	(-0.018)	0.003	(-0.015)
Landholding per adult equivalent	0.363**	(-0.167)	0.559***	(-0.196)	-0.395**	(-0.174)	-0.145	(-0.169)
Household's own land (1 = yes, 0 = no)	0.179	(-0.144)	0.120**	(-0.054)	0.516	(-0.348)	-0.313	(-0.409)
Access to markets and services								
One-way walking distance to all-weather road (minutes)	0.002	(-0.002)	-0.006**	(-0.003)	-0.001	(-0.002)	-0.004*	(-0.002)
One-way walking distance to *woreda* center (minutes)	0.001	(-0.002)	-0.006***	(-0.002)	0.003	(-0.002)	-0.012	(-0.002)
One-way walking distance to farmer training center (minutes)	-0.001	(-0.002)	0.001	(-0.003)	0.001	(-0.002)	-0.001	(-0.002)
One-way walking distance to credit center (minutes)	-0.003	(-0.002)	0.003*	(-0.002)	0.001	(-0.002)	0.002	(-0.002)
Social capital								
Participation in off-farm activities (1 = yes)	0.172	(-0.135)	-0.232	(-0.181)	-0.070	(-0.153)	-0.281**	(-0.136)
At least one household member migrates (1 = yes)	-0.267	(-0.188)	-0.541**	(-0.272)	-0.436**	(-0.209)	0.015	(-0.187)
Household participates in Debo (1 = yes)	-0.112	(-0.197)	0.411	(-0.304)	0.521***	(-0.194)	0.371*	(-0.204)
Household participates in Equib (1 = yes)	-0.193	(-0.169)	0.065	(-0.230)	-0.262	(-0.188)	0.170	(-0.171)
Household participates in Edir (1 = yes)	0.253	(-0.275)	0.987***	(-0.310)	0.491**	(-0.246)	0.057	(-0.223)
Household participates in women's associations (1 = yes)	0.531***	(-0.140)	0.408**	(-0.186)	-0.030	(-0.165)	0.038	(-0.141)

(Continued)

TABLE 5. Results of the multivariate probit model (Continued).

Independent variables	Technologies (dependent variables)							
	Multi-purpose trees		Orchards		Bunds/terraces		Gully rehabilitation	
	Coefficient		Coefficient		Coefficient		Coefficient	
District (*woreda*) dummies								
Woreda is Guder (1 = yes, 0 = no)	0.243	(-0.153)	-2.003***	(-0.378)	-0.928***	(-0.168)	-0.608***	(-0.150)
Woreda is Horo (Shambu) (1 = yes, 0 = no)	0.282*	(-0.161)	-0.404*	(-0.224)	-0.892***	(-0.185)	-0.369**	(-0.158)
Woreda is Diga (1 = yes, 0 = no)	0.411***	(-0.145)	0.505***	(-0.196)	-0.624***	(-0.185)	-1.044***	(-0.156)
Woreda is Farta (1 = yes, 0 = no)	-0.211	(-0.179)	0.808***	(-0.248)	-0.133	(-0.215)	0.795***	(-0.172)
Woreda is Gondar Zuria (1 = yes, 0 = no)	-0.454***	(-0.173)	-0.177	(-0.236)	-0.037	(-0.209)	1.053***	(-0.188)
Woreda is Fogera (1 = yes, 0 = no)	-0.690***	(-0.161)	-0.093	(-0.230)	-0.327**	(-0.163)	0.063	(-0.140)
Omitted (control) *woreda* is Jeldu	-		-		-		-	
Constant	-1.226***	(-0.441)	-2.952***	(-0.566)	0.207	(-0.479)	0.632	(-0.526)
Regression diagnostics								
Number of observations	654							
LR test of rho=0: χ^2 (6)	36.324***							
Wald (χ^2)	773.730							
Log pseudolikelihood	-1108.127							
Prob > χ^2	0.000***							

Notes: *, ** and *** indicates levels of significance at 10%, 5% and 1%, respectively. Figures within parenthesis are robust standard errors.

Social capital captured in the form of household membership and participation in informal and formal community networks is unobservable when used as a proxy of social capital. The age of the household head was found to be negatively and significantly correlated with adoption, and indicates that older farmers are less likely to adopt rainwater management technologies than younger farmers. This may be because young farmers are more able to provide the labor required to implement the technologies, and/or older farmers may have shorter planning horizons and are more risk-averse.

The results also disclose that male-headed households are more likely to adopt multi-purpose trees compared to female-headed households. While this is in agreement with the findings of Adesina et al. (2000), Kassie et al. (2009) reported that female-headed households are more likely to adopt sustainable agricultural technologies in Tanzania. Although the impact of gender on technology adoption is likely to be technology-specific and generalization is not possible (Kassie et al. 2009), our results indicate that male-headed households have a comparative advantage in the adoption of rainwater management technologies in the Blue Nile River Basin (Figure 7).

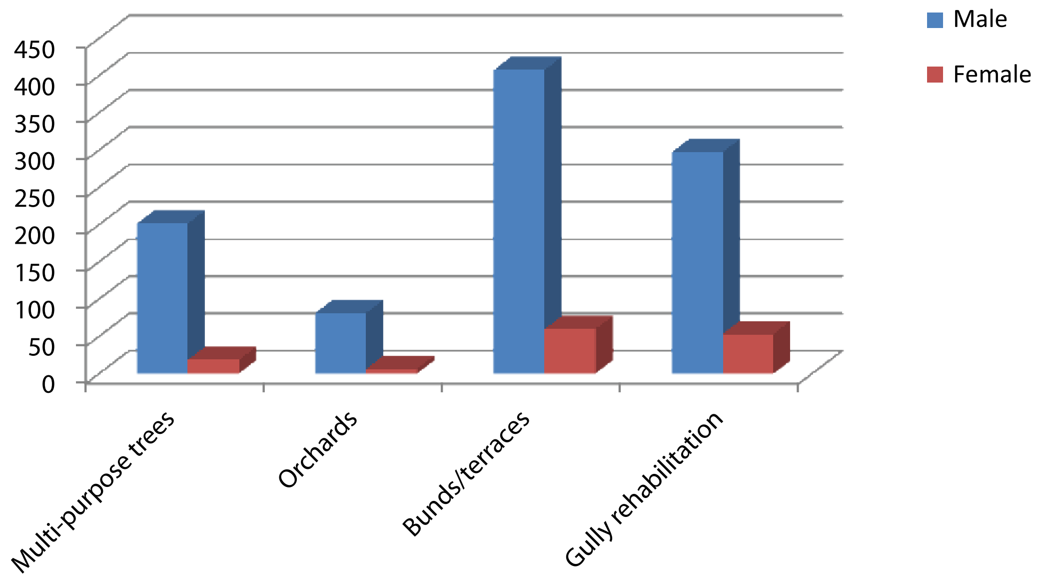
Most of the agricultural work is typically undertaken by men, while women are usually restricted to household and backyard activities. This suggests that men are more likely to have better farming experience. Farming experience

TABLE 6. Relationships between RWM technologies from the multivariate probit model regression equations (robust standard error is shown within parentheses).

Rainwater management technology	Multi-purpose trees	Orchards	Bunds/terraces
Orchards	ρ_{21} 0.448***(0.080)		
Bunds/terraces	ρ_{31} 0.154*(0.084)	ρ_{32} 0.232***(0.085)	
Gully rehabilitation	ρ_{41} 0.127*(0.069)	ρ_{42} - 0.006(0.076)	ρ_{43} 0.156**(0.071)

Note: *, ** and *** indicates level of significance at 10%, 5% and 1%, respectively.

FIGURE 7. Gender-disaggregated data on the adoption of rainwater management technologies.



usually increases the probability of technology adoption, because experienced farmers are more likely to have better access to information and knowledge of climatic conditions and coping mechanisms. In this context, the policy implication is that targeting women groups to address their constraints to actively participate in rural economic activities can have a significant impact on the adoption of rainwater management technologies. Furthermore, farmers with better experience and information are most likely to take initiatives in adopting and testing new technologies. Targeting of such progressive and model farmers during the promotion of technologies can, therefore, have a significant positive effect.

As expected, family size in adult equivalent has a positive and significant effect on the adoption of multi-purpose trees and orchards. This may imply that these technologies are labor-intensive and, therefore, households who have more labor are more likely to adopt them. Participation in off-farm activities has a significant negative effect on the adoption of gully rehabilitation, while migration is negatively related with the adoption of orchards and bunds/terraces. The implication is that both off-farm activities and migration are likely to compete for labor, which in turn could have been used to finance investment in rainwater management technologies. Since labor is a serious constraint, RWM technologies that require less labor or increasing labor efficiency may help to foster the adoption of these technologies.

Ownership of livestock has a significant positive impact on the adoption of orchards and bunds/terraces, implying that household wealth positively affects their decision to adopt a technology. On the other hand, ownership of land is positively correlated with the adoption of multi-purpose trees and orchards, but negatively correlated with the adoption of bunds/terraces. This is likely because a household that owns a large farm is less resource-constrained and has better options to diversify its income, which in turn may negatively affect willingness/incentive to invest in bunds/terraces.

Since multi-purpose trees and orchards are typically private investments as opposed to bunds/terraces and gully rehabilitation, which are commonly collective action activities usually carried out on a FFW basis, those who own more land are more likely to defect collective action as they may not expect to benefit from FFW payments. In this respect, the policy implication is that tenure arrangement and security is likely to facilitate long-term investments in rainwater management technologies.

Although some of the results are statistically insignificant, a longer distance to farmer training and credit centers (captured by the walking time to the nearest center) were found to negatively affect the adoption of rainwater management technologies. This implies that farmers who have better access to these services are better informed about the role of rainwater management technologies. Also, improved access to markets, extension services and credit centers have the potential to increase farmers' adoption of rainwater management technologies. Furthermore, access to credit centers and markets improves options to address liquidity constraints associated with investments in rainwater management technologies.

Social capital captured by household membership in social networks (group membership) was defined as binary (equal to 1 if the household is a member, and zero otherwise). The regression results suggested that social capital positively affects a household's decision to adopt rainwater management technologies. For example, a household's membership in Debo (a traditional labor sharing system) has a significant positive effect on the probability of adoption of bunds/terraces and gully rehabilitation. Similarly, a household's participation in Edir (a traditional peer support system) has a positive relationship with the adoption of orchards and bunds/terraces. Membership in a women's association also has a positive and significant effect on the adoption of multi-purpose trees and orchards. Women's associations commonly play the role of facilitating access to affordable (low interest rate) credit and technologies to their members. In general, the results suggest that social networks (both formal and informal) help members to use their peer support to overcome labor and/or credit constraints.

The fixed effects of *woredas* were included to capture unobserved site-specific factors. Results show that farm households in the Guder *woreda* are less likely to adopt orchards, bunds/terraces and gully rehabilitation than in Jeldu. Also, farm households in Horo (Shambu) and Diga are more likely to adopt multi-purpose trees, but less likely to adopt bunds/terraces and gully rehabilitation than those in Jeldu (the control *woreda*). The probability of adoption of orchards in Diga and Farta *woredas*, and gully rehabilitation in Farta and Gondar Zuria *woredas*, is also higher than in Jeldu. Finally, the results indicate that the adoption of multi-purpose trees in Gondar Zuria and Fogera, and bunds/terraces in Fogera, is less likely when compared to Jeldu. In general, the results suggest that it might be important to examine the socioeconomic and demographic characteristics of households, and biophysical suitability of watersheds, instead of promoting blanket recommendations for the adoption of rainwater management technologies.

Conclusions

The factors that influence the adoption of RWM technologies in the Blue Nile River Basin have been presented, in order to improve the understanding of why farmers do not adopt these technologies despite their suitability and potential benefits. The results indicate a joint correlation (interdependent) between RWM technologies, implying that the adoption decision of a specific technology is correlated with the adoption of another technology. This supports the assertion that it is important to consider packages of technologies.

The main variables influencing the adoption of rainwater management technologies in the Blue Nile River Basin include (i) demographic and family size of farm household (i.e., age, gender and marital status); (ii) education status; (iii) participation in off-farm activities; (iv) ownership of livestock; (v) ownership of land; (vi) access to markets, extension services and credit centers; (vii) social capital captured in the form of household membership, and participation in informal and formal community networks; and (viii) site-specific factors captured by the fixed effects of each location in the form of *woreda* dummies.

In general, the results suggest that it might be important to examine the socioeconomic and demographic characteristics of households, and biophysical suitability of watersheds, instead of promoting blanket recommendations for the adoption of rainwater management technologies. The regression results, together with insights gained from qualitative analysis, suggest that the most appropriate target groups for adoption of rainwater management technologies are those farm households with (a) limited landholdings; (b) limited access to markets, information and extension services; (c) bigger family size in adult equivalent, as an indication of labor endowment and the ability to engage in labor-intensive activities; (d) capital constraints and limited access to credit; (e) limited livestock and asset ownership; and (f) constraints faced by women to actively participate in rural economic activities, and by addressing these constraints. Correlation coefficients indicate that the adoption of RWM technologies are correlated, implying interdependence between different technologies. Thus, the adoption and promotion of rainwater management technologies should follow a holistic approach.

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Appendix

TABLE A1. Adoption rates of rainwater management technologies disaggregated by gender.

Rainwater management technology	Male		Female		Total	*T-test (significance of difference)*
	Number	Mean	Number	Mean		
Multi-purpose trees	202	0.380 (0.486)	19	0.204 (0.405)	221	0.000***
Orchards	82	0.157 (0.364)	7	0.087 (0.284)	89	0.033**
Bunds/terraces	408	0.745 (0.436)	60	0.602 (0.492)	468	0.003***
Gully rehabilitation	298	0.551 (0.498)	54	0.544 (0.501)	352	0.938
Total	990		140		1,130	

Notes: *, ** and *** indicates level of significance at 10%, 5% and 1%, respectively. Figures in parenthesis are standard deviations.

TABLE A2. Adoption of rainwater management technologies and ownership of land, slope, degradation and land use.

Rainwater management technology	Ownership		Slope			Degradation		Land use	
	Public land	Private land	Flat	Gentle slop	Steep slop	Degraded	Less degraded	Grassland	Cropland
Multi-purpose trees	36	201	92	102	41	143	92	104	131
Orchards	1	98	41	55		52	44	31	65
Bunds/terraces (without vegetation)	45	322	31	281	165	185	292	104	373
Bunds/terraces (with vegetation)	21	44	8	53	29	42	48	35	55
Shallow/hand-dug wells		33							
Ponds	1	22							
River diversions	85	27	69	41		69	41		110
Area enclosures	101	29	24	62	35	78	43	121	
Gully rehabilitation	18	278	19	103	175	205	92	204	93

TABLE A3. Reasons for not adopting rainwater management technologies: Frequency of farmers' response.

	Multi-purpose trees	Orchards	Bunds/terraces (without vegetation)	Bunds/terraces (with vegetation)	Shallow wells	Ponds	River diversions	Area enclosures	Gully rehabilitation
No problem of land degradation	19	11	23	9	10	9	13	13	18
Availability of sufficient rainfall	12	10	15	5	17	13	15	8	10
Have enough land	17	18	18	7	15	14	13	17	14
Shortage of land	56	44	51	20	34	34	36	49	32
Lack of labor	37	31	46	17	44	42	31	25	43
It is labor- and time-intensive (tiresome)	17	16	31	12	22	36	24	19	39
Availability of sufficient surface water/groundwater	14	13	11	5	28	18	16	8	9
Lack of awareness about the technology	54	40	36	12	35	34	19	31	24
Technology is not suitable on my land	32	47	28	10	42	41	50	32	32
Lack of capital/credit	43	38	44	16	13	37	27	25	27
Not profitable to invest	12	15	17	5	23	15	9	14	14
Lack of proper technical advise	40	33	32	11	10	24	17	24	23
I have better options	6	7	8	3	13	8	7	7	7
Limited access to markets	19	14	15	5	24	11	8	9	11
Lack of cooperation with neighborhood	29	24	33	12	NA	25	25	28	31

TABLE A4. Number of sample households that adopted a combination of RWM technologies and level of correlation between these technologies.

Combination of RWM technologies	Number of adopting households	Correlation coefficient and significance level
Multi-purpose trees and orchards	55	0.235***
Multi-purpose trees and bunds/terraces	173	0.106**
Multi-purpose trees and gully rehabilitation	109	0.065
Orchards and bunds/terraces	82	0.181***
Orchards and gully rehabilitation	48	0.001
Bunds/terraces and gully rehabilitation	277	0.171***
Multi-purpose trees, orchards and bunds/terraces	49	NA
Multi-purpose trees, orchards and gully rehabilitation	22	NA
Multi-purpose trees/gully rehabilitation and bunds/terraces	84	NA
Orchards, gully rehabilitation and bunds/terraces	44	NA
Multi-purpose trees, orchards, bunds/terraces and gully rehabilitation	18	NA

Notes: ** and *** indicates level of significance at 5% and 1%, respectively. NA = not applicable.

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