Determinants of Farm-level Adoption of Water Systems Innovations in Dryland Areas: The Case of Makanya Watershed in Pangani River Basin, Tanzania

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Abstract

Water system innovations such as rainwater harvesting involve abstraction of water in the upper catchments. Increasing adoption of rainwater harvesting in the riparian catchments could have hydrological impacts on downstream flows in the river basin, but it is assumed to have overall gains and synergies when efficient use of rainwater is optimized at farm-level. This paper examines the main determinants of adoption of water system innovations with specific emphasis on the intensity of adoption and adoption lag, using a cross-sectional sample of 234 farmers in the Makanya watershed. Censored Tobit models were used to estimate the coefficients of intensity of adoption and adoption lag of water system innovations. Group networking, years spent in formal education, age of respondent, location and agricultural information pathways were found to be major determinants of intensity of adoption at farm-level. It was also found that intensity of adoption and frequency of attendance to collective action are strong determinants of adoption lag of water system innovation in Makanya watershed. Empirical knowledge of the determinants of adoption of water system innovations is critical for an effective scaling out of best practices of water harvesting in the Basin.

Key words: Intensity of adoption, Adoption lag, Water System Innovations (WSIs),

Introduction

Smallholder System Innovations and River Basin Management

Smallholder water system innovations (WSIs) such as supplementary irrigation and rainwater harvesting involve abstraction of water from the catchment upstream and may have hydrological impacts on downstream water availability. The primary goal of river basin management should be to enable rivers and watersheds to perform their many vital ecological functions and to benefit people who depend on them for the maintenance of their livelihoods. In developing countries community-based river basin water management centers on rainfall, not on 'managed' water. Here people depend on local water-harvesting and storage structures and, consequently, their understanding of ownership and rights over water relates more easily to rainfall than to diverted water. Historically, communities in peninsular India and Sri Lanka have met this challenge by digging small local reservoirs or tanks, to collect monsoonal water for use throughout the year. There is evidence that diverting rainwater to a large number of small water-harvesting structures in a catchment captures and stores more rainfall closer to communities than having a large reservoir downstream. The bottom line is that despite the negative effect rainwater harvesting might have on the eco-hydrology, it is a promising option for upgrading the productivity of rainfed agriculture in dry land tropics.

Downstream access to water as a result of increased water withdrawals upstream is an issue of concern, but it is assumed that there are overall gains and synergies to be made by maximizing the efficient use of rainwater at farm level (Rockstrom, 2001). Up-scaling of rainwater harvesting (RWH) - increasing adoption - could have hydrological impacts on river basin water resources management. Research on water harvesting systems in the arid Negev desert by collection of local run-off in many cascading small water harvesting storage systems was found to increase water use efficiency at the downstream end of a catchment (Evanari *et al.,* 1971). Rockstrom *et al.* (2004) argues that there are large opportunities to improve rural livelihoods through the adaptive adoption of smallholder water system innovations.

Adoption of smallholder water system innovations

As African agriculture remains largely rainfed and as water scarcity issues are receiving much more prominence, more work on technology development and adoption studies in this area is anticipated (Place *et al.,* 2002). Extensive research indicates that integrated soil and water management and technological innovations in water management can contribute to significant upgrading of rainfed agriculture, which is the dominant livelihood base in large parts of Sub-Saharan Africa (SSA) (Rockstrom and Falkenmark, 2000; Hatibu *et al.,* 1999; Agarwal and Narain, 1997). The RWH system innovations in the semi-arid areas of East Africa constitute about 30% of all farmers' innovations, while water management innovations more broadly comprise half of the total (Critchley, 1999). A wider range of WSIs already exist and are being used successfully by farmers in the Makanya watershed (Masuki *et al.,* 2004). But despite many promising technologies, some farmers often fail to adopt them (Knox and Meinzen-Dick, 1999). This paper aims to address the reasons for that.

Intensity of adoption of technology

Intensity of adoption refers to the number of technologies practiced by the same farmer. The intensity of adoption of different technologies is measured by a variable that represents the breadth of technology use within a particular stage of production. Saha *et al*. (1994) recognized that producers' adoption intensity is conditional on their knowledge of the new technology and on their decision to adopt. They found that larger and more educated operators are likely to adopt more intensively. Abadi Ghadim (2000) conducted a study that comes close to implementing and estimating a complete set of risk impacts related to adoption. Results showed that some determinants of the decision to adopt the innovation are different from those that determine the decision regarding the intensity of adoption. Firms that employ a wide range of advanced technologies - adoption intensity - have mastered a larger skill set and are hypothesized to have shorter adoption lags than those using only one or two technologies (Baldwin and Rafiquzzaman, 1998).

Technology adoption lag

Sociologists describe adoption as a gradual process which involves sequential stages. Researchers have attempted to use these theories to develop models for evaluating adoption path and time lag between initial awareness of technology to actual use of the innovation by the adopter. Adoption lag refers to the length of delay between a farmer first becoming aware of the existence of a new technology and his/her adoption (Nabseth and Ray, 1974). Once one has developed the best technical means, it is little wonder that one considers their adoption unquestionably desirable, but farmers tend to be a bit recalcitrant. Hence, there tends to be a 'time lag' between the moment at which a farmer learns about an innovation and the time when he or she adopts it (de Buck *et al.,* 2001). Linder *et al*. (1979), in their work to develop an expression for explaining the time lag between stages of adoption, concluded that the time lag between awareness and adoption is related to the variance of actual profit. Lindner (1980) assumed that adoption lag is attributed to keenness of farmers to search for and learn about new innovation. The second type of adoption studies are temporal studies that are concerned with the determinants of the timing of adoption. A new technology passes through several stages of assessment before it is adopted.

This paper investigates the main determinants of adoption of water system innovation with a focus on intensity of adoption and adoption lag, using a cross-section of farmers in Makanya watershed.

Methodology

Description of Research Sites

Data were collected from an extensive watershed with varying biophysical, socio-economic and farming conditions. The Makanya watershed is located in Same District within the Pangani River basin hydrological system south of Mount Kilimanjaro. The study covered five villages located in the up-, mid- and down-stream of a single watershed extending from the Pare Mountains (composing the world famous Eastern Arc Mountains) to the Pangani River. Villages in the upland include Chome and Vudee, those in the midland Bangalala and Mwembe, and in the lowland is Makanya. Same district is located between latitudes $4^{\circ}\ 8^{\prime}$ and $4^{\circ}\ 25^{\prime}$ South and longitudes $37^{\circ}\ 45^{\prime}$ and $37^{\circ}\ 54^{\prime}$ East (Figure 1). It lies along the Nairobi-Dar-es-Salaam highway. The watershed course opens in the lowland about 140 km from Moshi town. The watershed lies at an elevation between 600m and 2500m above mean sea level in the lowland and upland respectively.

The rainfall pattern is bimodal, with mean annual total of 400-600 mm in the lowland to midland and around 800-1200mm in the upland. This rainfall pattern distinguishes the watershed into semi-arid mid- to lowland and sub-humid upland drylands. The short rains start in November and extend to January. The long rains start in March and extend to May and are more reliable. Evaporation varies between 3.0-5.4 mm d^{-1} with an annual long-term average of 1,575 mm y^{-1}. The study area has an erratic rainfall regime particularly in terms of distribution, and high probabilities of the occurrences of both seasonal droughts and intra-seasonal dry-spells. This situation negatively affects the performance of agriculture, which is the mainstay of people's livelihoods. However, farmers are not passive victims of such climate variability, as they have developed water systems innovations (WSIs) that have enabled them to survive in the area.

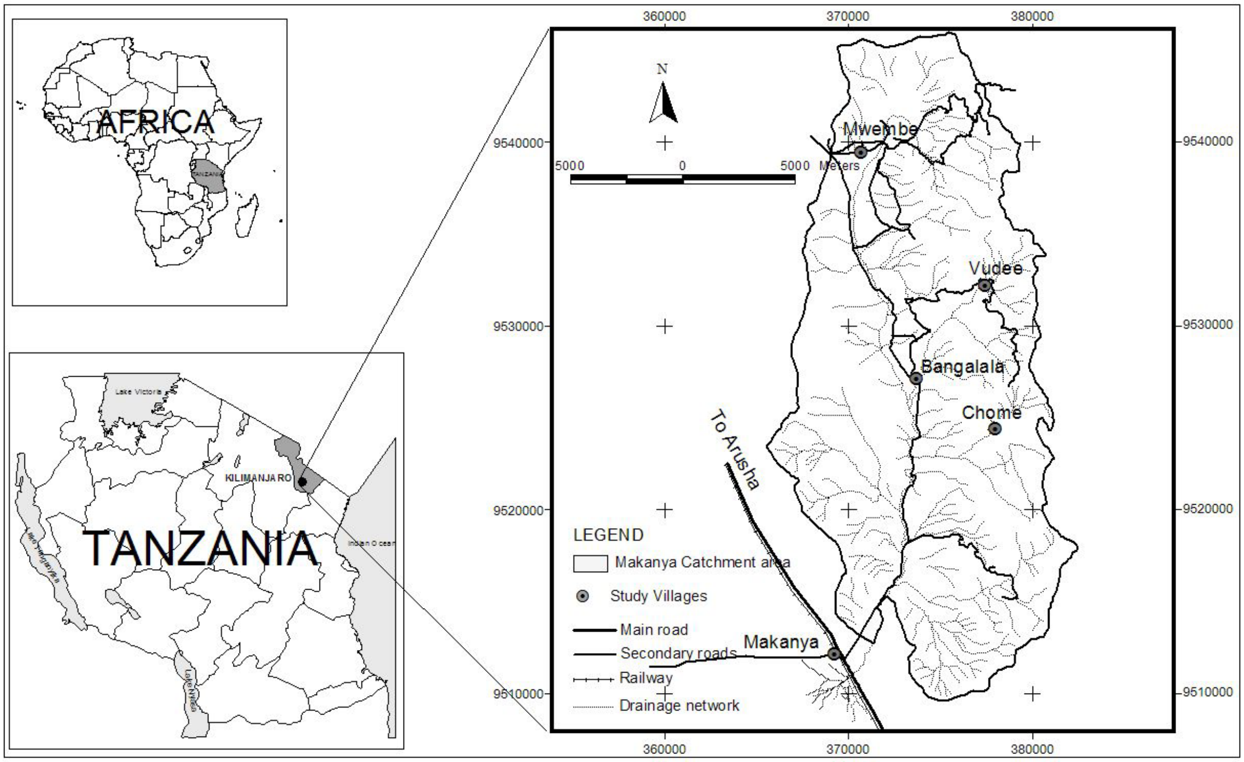

Figure 1. Geographical location of the study area

Methodological Approach

Design of the study

It is important to note that the study was framed on a perspective different from conventional household studies. The central aspects of the study are the intensity of adoption and the adoption lag of WSIs, which are 'household' variables. This condition shaped the whole study, particularly in the design of research instruments and analytical approaches. The study made use of both participatory approaches and structured interviews to collect the information required to address the hypotheses. Participatory approaches included discussion with village leaders and key informants and focus group discussions in of each the study villages. In order to collect quantitative community-related information, structured household interviews with a mixture of closed and open-ended questions were used. Information collected through participatory approaches is very useful to enrich the understanding and interpretation of results obtained through structured household interviews. The questionnaire survey involved interviewing random samples of households proportionally selected from each village of the study watershed as shown in Table 1.

Table 1. Structure of the sample for different villages in the watershed

Position of respondent	Makanya		Mwembe		Bangalala		Vudee		Chome	
	n	%	n	%	n	%	n	%	n	%
Household head	29	71	25	58	33	60	33	67	36	78
Spouse	11	27	17	40	20	36	13	27	10	22
Other member	1	2	1	2	2	4	3	6	-	-
Total	41	100	43	100	55	100	49	100	46	100

Data Analysis

The Tobit model was used to estimate the intensity and determinants of adoption of water system innovations at farm level because of the censored nature of distribution in the adoption of water system innovations.

In a standard regression model, the dependent variable is generally assumed to take on any value within the set of real numbers and the probability of any particular value is zero. In the dichotomous Probit model, the dependent variable assumes only two values, i.e. 0 and 1, each of which is assigned a probability mass. Tobin (1958) proposed a limited dependent variable model, later called the Tobit model by Goldberger (1964) to handle dependent variables which are combinations of these two cases, specifically mass points at the low end called the limit value and continuous values above the limit. The limit of the variable can be due to truncation or censoring of observations in the data set. Truncation occurs when the sample data are drawn from a subset of a larger population under consideration. Censoring, on the other hand, is essentially a defect in the sample data brought about by some random mechanism, i.e. Y assumes a value Y* if it falls within some specified range, otherwise Y is equal to a limit value often set to zero. This implies that outside the specified range, the true values of Y* become masked and are all transformed to a single value which is the limit. As a result, the dependent variable contains zero values for a significant fraction of the observations. To analyze these kinds of problems, the model is specified as follows:

$$\begin{aligned} \mathrm{Y}_{it} &= \beta \mathrm{X}_{it} + \mu_{it} \quad if \quad \beta \mathrm{X}_{it} + \mu_{it} > 0 \\ \mathrm{Y}_{it} &= 0 \qquad\qquad\quad if \quad \beta \mathrm{X}_{it} + \mu_{it} \leq 0 \end{aligned}$$

Where Y_{it} = Dependent variable
X_{it} = a vector of exogenous explanatory variable
μ_{it} = residual effect
β and σ^2 = estimated maximum likelihood analysis

Tobit model parameters do not directly correspond to changes in the dependent variable brought about by changes in independent variables. To obtain the correct regression effects for observations above the limit, the β coefficients must be adjacent as follows:

$$\frac{\partial \mathrm{E}\left(\mathrm{Y}/_{X\,it} \right)}{\partial \mathrm{X}_i} = \Phi\left(\beta \mathrm{X}_i /_{\sigma} \right) \beta_i$$

Results and Discussion

Intensity of adoption of water system innovation

Table 2 shows the results of maximum likelihood estimations of the intensity of adoption. Results of Tobit run shows that seven out of eleven estimated coefficients of intensity of adoption of WSIs exhibited positive sign and four were significant at 1%. The coefficients of group networking, number of years spent in formal education, age of head of household and pathways of agricultural information are positively and highly significant ($P \leq 0.01$) to the intensity of adoption of water system innovations.

Table2. Maximum likelihood estimations of intensity of adoption

Variable	Coefficient of intensity	Std error
Group networking	0.32039***	0.0899
Sex (dummy)	- 0.05441	0.1775
Years in formal education	0.07901***	0.0257
Age of head of household	0.01579***	0.0037
Interaction with people of different backgrounds	- 0.00004	0.0009
Interaction with people of the same background	- 0.00065	0.0011
Location (dummy)	0.25310	0.1857
Perception of social trust	0.00045	0.0008
Frequency of attending collective action	- 0.00111	0.0026
Agricultural information pathway	0.21925***	0.0678
Percent of institution-called meetings attended	0.00014	0.0003

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

Group networking is a form of social capital that involves interaction and interconnectedness in a society. It aggravates social participation such as membership in local organizations and has a positive relationship with the use of conservation practices. Abd-Ella *et al.* (1981) and Korsching *et al.* (1981) also experienced similar findings.

Number of years spent in formal education is one of the important determinants of intensity of adoption of WSIs. Education catalyses the process of information flow and leads the farmer to as wide as possible, the different pathways of getting information about a technology. The more information pathways the farmer has, the more the farmer intensifies adoption of WSIs. Indeed, studies of innovation adoption and diffusion have long recognized information as a key variable, and its availability is typically found to correlate with adoption (de Harrera and Sain, 1999). Information becomes especially important as the degree of complexity of conservation technology increases (Nowak, 1987). Agbamu (1995) indicates that contact alone will not promote adoption if information dissemination is ineffective, inaccurate or inappropriate. Information sources that positively influence the adoption of technologies can include other farmers, the media, meetings and extension officers. Studies have not always shown that the ease of obtaining information correlates with adoption. Saha *et al*. (1994) stresses the fundamental role played by the quality of information on the decision to adopt or not, and on the intensity of adoption of a new technology in a context where adoption is divisible and significant risks are present. Ersado (2001) reports the adoption of more technologies - intensity of adoption - increases as household head education level increases.

Our findings show that age correlated well with intensity of adoption of WSIs. This implies that as the farmer gets older he/she tends to intensify adoption of innovation in his/her farm. We simply attribute this to the experience of the farmer in farming activities, which other studies have found to be important in adoption of technology.

Adoption lag of water system innovations

Table 3 shows the results of maximum likelihood estimations of adoption lag of water system innovation. Results of the Tobit run show that five out of twelve estimated coefficients of adoption lag of WSIs exhibited positive sign and six were significant at 10% or better. The coefficient of intensity adoption ($P \leq 0.01$) was found to be most important determinant of adoption lag of WSIs in Makanya watershed, followed by frequency of attending collective action ($P \leq 0.05$). The sex of head of household, number of years spent in formal education, age of head of household and pathways of agricultural information were significant at $P \leq 0.1$. However, the numbers of years spent in formal education and age of the head of household had negative coefficient estimates, implying that they have positive influence on the adoption process.

Table 3: Maximum likelihood estimations of adoption lag models

Variable	Coefficient	Std error
Intensity of adoption	5.887***	1.182
Group networking	- 0.973	1.572
Sex (dummy)	5.015*	3.044
Year of formal education	- 0.835*	0.453
Age of head of household	- 0.111*	0.067
Interaction with people of different background	- 0.022	0.019
Interaction with people of the same background	- 0.004	0.020
Location (dummy)	- 3.847	3.212
Perception of social trust	- 0.011	0.015
Frequency of attending collective action	0.109**	0.044
Agricultural information pathway	2.203*	1.179
Percent of institutions called meetings attended	0.002	0.004

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

Intensity of adoption has influence on adoption lag. Adoption intensity is the number of technologies adopted by each respondent farmer. Having more than one technology in a plot increases the time lag for adoption of WSIs because it lengthens the adoption process passing through different stages for each technology and hence adoption sequence. Ersado (2001) indicated that the decision and intensity of technology adoption are highly correlated with the sequential nature of adoption – adoption lag. Contrary to the findings of Baldwin and Rafiqquzaman (1998), who found that for firms with a wide range of technologies, adoption intensity has shortened the adoption lag more than for those who have one or two. This seems to be true for adoption at organization level and not for adoption at farm level.

Sex (dummy) shows that female-headed households have positively influenced adoption lag of water system innovation. This is attributed to decision-making mechanisms which seem to be weak in female heads of households. The number of years the head of household spent in formal education and age of the head of household were found to exhibit a negative relationship with adoption lag. The head of household who has a higher lever of education is likely to adopt a water system earlier, therefore shortening the adoption lag. Education exposes someone to information and therefore creates awareness, which is a very important stage in the adoption of innovation. The older the head of household, the shorter the time lag in adoption. Our findings appear contrary to most studies that report that younger farmers tend to adopt technologies much faster than older farmers. For example Ersado (2001) found that among other factors that influence adoption of innovation in Ethiopia, the age of the head of household and education level were found to positively and significantly affect the probability of sequencing choices – adoption lag. The higher the frequency of attending collective activities, the higher the time lag in adopting WSIs. The time lag for adoption of WSIs is positively and significantly influenced by the number of pathways used to convey agricultural information.

Conclusions

Our study has highlighted that group networking, number of years spent in formal education, age of head of household and pathways of agricultural information all affect the intensity of adoption positively and significantly. This suggests that river basin management strategies should consider strengthening collective action where people create interconnectedness among themselves, keeping in mind their education level and age. Also, the pathways for agricultural information should be multiple and variable to be able to reach a cross-section of primary stakeholders in the river basin. As several other studies have indicated that the rate of adoption of WSIs is still low, consideration of these factors in the scaling out of WSIs is predicted to improve their adoption and thus intensify management of water resources in the Pangani River Basin.

Furthermore, smallholder farmers, such as those in the Makanya watershed who have developed their own water system innovations over years, now view group networking and information pathways as important determinants in the adoption of WSIs. Agencies involved in promoting water management innovations, including the Pangani Basin Water Office (PBWO), thus need to emphasize community-based organizations and multiple pathways for the dissemination of proven natural resources management innovations in order to achieve higher rates of adoption of water system innovation.

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