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Factors Influencing Intensity of Adoption of Integrated Water Management Innovations in the Semi-Arid Areas of North-eastern, Tanzania

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Abstract: The semi-arid areas of north-eastern Tanzania are faced by regular incidences of intra-seasonal dry spells which pose negatively impact on crop yields. The situation has forced farmers to practice different types of innovations including *in situ* capture and management of rainwater, collection, concentration, diversion and/or storage of run-off to mitigate the problems. This paper examines the main factors influencing intensity of adoption of water management innovations. The study was conducted through a cross-sectional survey in Makanya watershed, involving 234 farmers. Censored Tobit model was used to estimate the coefficients of intensity of adoption of the innovations. Intensity of adoption of the innovations was found to be between two and four. Most households (78.3%) had at least two innovations per plot, such as diversion canals, borders basin (sunken beds) and large planting pits, complimented with use of farm-yard manure, deep tillage, mulching and cover crops. The adoption intensity was higher in the uplands, with more than 56.7% of farmers having four or more innovations in their farms compared to 30.8% and 41.7% in the lowlands and midlands, respectively. Group networking, years spent in formal education, respondent's age and agricultural information pathways were found to be the major factors influencing the adoption intensity at farm-level. Considering these factors in the scaling out of the innovations is expected to improve their adoption and thus intensify management of water resources in semi-arid watersheds with similar settings like Makanya. This is critical for an effective promotion of best practices of integrated water management systems at landscape level.

Key words: Water system innovations, management, rainwater, smallholder, water resources.

1. Introduction

Smallholder water system innovations (WSIs) are dominated largely by rainwater harvesting which is usually employed as an umbrella term describing a range of methods of collecting water flows and conserving various forms of run-off water originating from ephemeral water flows during rainstorms for productive use [1]. The WSIs are none than conventional soil and water management innovations. They include all indigenous and novel technologies and methodologies for improved agricultural water management, for crop and livestock production. These innovations include water harvesting, drip irrigation, precision agriculture and conservation farming technologies aiming at improving water productivity while conserving resources [2]. They are mainly used to capture and store water and moisture to improve agricultural water productivity. Farmers in semi-arid areas of north-eastern Tanzania are faced with regular occurrences of intra-seasonal dry spells which adversely impact crop yields. These farmers practice different types of WSIs, including *in situ* capture and management of rainwater, collection, concentration and/or diversion of run-off and collection and storage of run-off [3], as mitigative measures to reduce the ever occurring intra-seasonal dry spells.

Evidence is well documented from around the world of successful innovative technologies and methodologies to improve agricultural productivity in smallholder rain-fed farming systems [2]. One of the primary goals of watershed management should be to enable water resources to perform their many vital ecological functions and to benefit people who depend on them for the maintenance of their livelihoods. This includes inducing farmers to adopt innovative water management practices in their farming systems to harness rain and runoff water for mitigation of intra-seasonal dry spells. In developing countries community-based watershed management focuses 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 [4]. 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. It has offered 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 [4]. 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 [5]. Despite maximizing water use efficient at watershed level, water harvesting of surface runoff added as supplementary irrigation was reported to improved maize yields as a result of dry spell mitigation [6], and through adaptive adoption, smallholder water system innovations provide large opportunities for improved rural livelihoods [2].

As African agriculture remains largely rain fed, and as water scarcity issues are receiving much more prominence, more work on technology development and adoption studies in this area is anticipated [7]. Extensive research indicates that integrated soil and water management and technological innovations in water management can contribute to significant upgrading of rain fed agriculture which is the dominant livelihood base in large parts of Sub Saharan Africa (SSA) [8, 9]. 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 comprised half of the total [10]. A wider range of WSIs already exist and are being used successfully by farmers in the Makanya watershed [11]. But, despite many promising technologies, some farmers often fail to adopt them [12].

Intensity of adoption refers to the number of technologies practiced by the same farmer in a plot. 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 and colleagues [13] 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 [14] conducted a study that comes close to implementing and estimating a complete set of risk impacts related to adoption. Results showed that some factors influencing decision to adopt the innovation are different from those that influence the decision regarding the intensity of adoption. The objective of this study was to identify the main factors that influence adoption of water system innovation with focus on intensity of adoption in the north-eastern region of Tanzania.

2. Materials and Methods

2.1 Study Sites

The study was conducted in the Makanya watershed, located in Same District within the Pangani River basin hydrological system south of Mount Kilimanjaro, in Tanzania. Same district lies between latitudes 4°8′ and 4°25′ south, and longitudes 37°45′ and 37°54′ East along the Nairobi-Dar-es-Salaam highway (Fig. 1). The study covered five villages located in the up-, mid- and down- stream of a single watershed extending from the Pare Mountains (composing the globally famous Eastern Arc Mountains) to the Pangani River. Villages in the upland include Vudee and Marieni, those in the midland are Bangalala and Mwembe, and in the lowland is Makanya. The watershed course opens in the lowland about 140 km from Moshi town. The watershed lies at an elevation between 600 m and 2,500 m 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 800-1,200 mm 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 $mm \cdot d^{-1}$ with an annual long-term average of 1,575 $mm \cdot y^{-1}$. Virtually, the study area has 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.

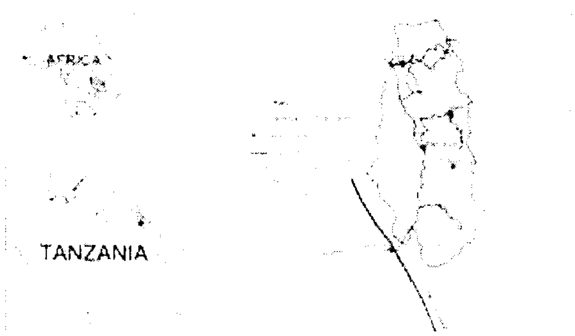

Fig. 1 Location of the study villages within the Makanya watershed.

2.2 Methodological Approach

2.2.1 Design of the Study

The study made use of both participatory approaches and structured interviews to collect the information Participatory approaches included discussions with village leaders, key informants and focused group discussions in each of 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 the results obtained through structured household interviews. The questionnaire was pretested in Makanya, Bangalala and Mwembe villages for its validity to collect the required information. A total of 234 farmers were sampled randomly from the five villages. The questionnaire survey involved interviewing random samples of households proportionally selected from each village of the study watershed.

The central aspect of the study is the intensity of adoption of WSIs, which is among the 'household' variables. This condition shaped the whole study particularly in the design of research instruments and analytical approaches. The data for intensity of adoption was collected during household survey by asking the number of innovations practiced in each plot.

2.3 Data Analysis

The Tobit regression model was used to analyze and estimate the factors influencing intensity of adoption of water system innovations at farm level. 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.

Intensity of adoption of WSIs does not have a specific measurement but occurs in a measurement that exceeds some threshold and it not easy to know by how much its distribution is censored. Given the censored nature of distribution in the intensity of adoption of WSIs an appropriate approach for modelling censored dependent variables using maximum Likelihood Estimation (MLE) procedure is Tobit model [15]. Tobin [16] proposed a limited dependent variable model, later called the Tobit model by Goldberger [17] 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 advantage of Tobit Model over dichotomous choice models such Logit and Probit is that it permits determination of not only the probability of adoption but also the intensity of adoption once the adoption decision has been made. Thus Tobit model allows simultaneous identification of factors that affect adoption and intensity of adoption of innovation. The approach has been intensively used in adoption and impact studies [18, 19]. 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:

$$\begin{aligned} Y_{it} &= \beta X_{it} + \mu_{it} \quad & if \quad \beta X_{it} + \mu_{it} > 0 \\ Y_{it} &= 0 \quad & if \quad \beta X_{it} + \mu_{it} \leq 0 \end{aligned} \tag{1}$$

Where Y_{it} = Dependent variable (is the number of WSIs implemented in a plot at a particular time),

X_{it} = a set if independent variables representing key attributes of farm-level socio-economic characteristics,

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:

$$\frac{\partial E\left(Y/_{X_{it}}\right)}{\partial X_i} = \Phi\left(\beta X/_{\sigma}\right)\beta_i \tag{2}$$

The independent variables included in the Tobit model are described in Table 1. The independent variables have varying effects on intensity of adoption of technologies. It was hypothesized that these independent variables have influence on the intensity of adoption. From the adoption Meta theory [20], some factors are said to affect adoption positively or negatively. For instance, membership in farmer association, network with neighbours and friends and interaction with professionals may affect adoption positively. Farmers were asked on their involvement in any community/farmer group; what was their perceived level of trust among group members; how many sources information on the WSIs they implement in their farms; their interaction within the group and/or other farmers within the community; their interaction with other people who normally visit the villages (like students and their supervisors from abroad and other visitors who came to see the implementation of water system innovations in the area).

Table 1 Description of independent variable included in regression model.

Variable	Variable description	Measurement
GROUPNET	Group networking	Yes = 1; No = 3; Don't know = 3
SEXHH	Sex (dummy)	Male = 1; female = 2
FORMAEDU	Year of formal education	Years
AGEHH	Age of head of household	Years
DIFPPINT	Interaction with people of different background	Very low = 1; low = 2; average = 3; high = 4; very high = 5
SAMPPINT	Interaction with people of the same background	Very low = 1; low = 2; average = 3; high = 4; very high = 5
LOCATION	Location (dummy)	Uplands = 1; Midlands = 2; Lowlands = 3
SOCTRUST	Perception of social trust	Very low = 1; low = 2; average = 3; high = 4; very high = 5
COLLEACT	Frequency of attending collective action	Number of meetings attended
AGRINFO	Agricultural information pathway	Number of information sources
ATTNDMET	Per cent of institutions called meetings attended	Percentage

3. Results and Discussion

3.1 Intensity of Adoption of Water System Innovation

Table 2 shows the intensity of adoption of WSIs. The intensity varies with the toposequence across the Makanya watershed. Generally, most households (78.3%) adopted at least two innovations per plot. The adoption intensity was higher in the uplands whereby more than 56.7% of farmers have 4 or more innovations in their farms as compared to 30.8% in the lowlands and 41.7% in the Midlands. Most farmers in the lowlands practice run-off diversion due to the rainfall shortage in the lowlands farmers depend much on spate irrigation whose water is diverted from ephemeral streams which run from the uplands during heavy storms. Therefore this innovation goes together with diversion canals, borders basin (sunken beds) and large planting pits that hold water around the plant. Some other innovations to compliment this include use of farm yard manure, deep tillage, mulching and cover crops. This innovation also goes together with charco-dams for storing the diverted water and it is only common in the lowlands. This is due to the fact that much as the lowlands is highly constrained in terms of water and moisture compared to the midlands and uplands attributed to the biophysical nature of the landscape which is almost flat and receives very little rainfall, thus, this area has less opportunities for WSIs as compared to uplands and midlands. Therefore most farmers in the lowlands implement fewer innovations in the same farm plot (mainly diversion, conveyance and storage type) but strategic to coping with drought shock that normally strikes the area before the crops reach maturity.

During key informants and focus group discussions the farmers explained that the main reason for intensifying their WSIs adoption lies behind tapping every opportunity to curb the little water they receive in their areas. On the other hand they also link a number of reasons to having various innovations in the same plot such as controlling soil erosion for the farms, which are on slopes (mostly in the midlands and uplands) and improving soil fertility.

3.2 Factors Influencing Intensity of Adoption

Table 3 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%.

Table 2 Intensity of adoption of WSIs in the Makanya watershed (%).

Landscape position	Number of WSIs adopted per plot				
	< 2	2	3	4	> 4
Lowlands (Makanya)	18.3	27.5	23.3	18.3	12.5
Midlands (Mwembe and Bangalala)	35.0	13.3	10.0	16.7	25.0
Uplands (Vudee and Marieni)	11.7	10.0	21.7	25.0	31.7
Total	21.7	16.9	18.3	20.0	23.1

The coefficients of group networking (GROUPNET), number of years spent in formal education (FORMAEDU), age of head of household (AGEHH) and pathways of agricultural information (AGRINFO) are positively and highly significant ($P \leq 0.01$) to the intensity of adoption of water system innovations.

Group networking is a form of social capital that involves interaction and interconnectedness in a society. It intensifies social participation such as membership in local organizations and has a positive relationship with the use of conservation practices. The findings by Tumbo and colleagues [21] reported that group networking in water management was higher indicating water management groups as being more important. Water management groups were involved in water management issues entailing allocation and maintenance of water infrastructure. Abd-Ella and colleagues [22] and Korsching [23] also obtained similar findings.

Number of years spent in formal education is one of important factors influencing 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 [24]. Information becomes especially important as the degree of complexity of the conservation technology increases [25]. Agbamu [26] indicated 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; media; meetings and extension officers. Studies have not always shown that the ease of obtaining information correlates with adoption. Saha and colleagues [13] stressed 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 [27] reported 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 experience of the farmer in farming activities, which other studies have found to be important in adoption of technology.

4. Conclusion

The farmers in the Watershed are practicing at least one type of WSI, which emphasises the importance of moisture and water management in semi-arid rain-fed

Table 3 Maximum likelihood estimations of intensity of adoption.

Variable	Variable description	Coefficient	Std error
GROUPNET	Group networking	0.32039***	0.0899
SEXHH	Sex (dummy)	- 0.05441	0.1775
FORMAEDU	Year of formal education	0.07901***	0.0257
AGEHH	Age of head of household	0.01579***	0.0037
DIFPPINT	Interaction with people of different background	- 0.00004	0.0009
SAMPPINT	Interaction with people of the same background	- 0.00065	0.0011
LOCATION	Location (dummy)	0.25310	0.1857
SOCTRUST	Perception of social trust	0.00045	0.0008
COLLEACT	Frequency of attending collective action	- 0.00111	0.0026
AGRINFO	Agricultural information pathway	0.21925***	0.0678
ATTNDMET	Percent of institutions called meetings attended	0.00014	0.0003

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

agriculture. Considering intensity of adoption which varies from one to above four, someone can arrive at this conclusion that causes of technology adoption at household level are embedded within the household capital endowments (livelihoods assets). There are significant positive relationships between adoptions of WSIs with group networking, number of years spent in formal education, age of head of household and pathways of agricultural information. This implies that adoption of WSIs is likely to increase with increased or improved conditions of the above factors.

The higher the group network intensity the higher the adoption of WSIs thus involvement into the networks intensifies the exposure, social learning, and knowledge and information sharing. Membership of the heads of household in groups and networks is a strong factor influencing adoption of the innovations which have landscape level outcomes. These are the innovations whose implementation requires decisions of more than one household. Education determines levels of exposure and information about technology, thus the level of formal education and additional training in the household were very important factors influencing adoption of WSIs. The age of household head depicts years of experience in farming thus important for adoption of WSIs especially the indigenous types.

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