ABSTRACT

Agricultural productions of smallholder farmers are vulnerable to rainfall shortage and variability in Ethiopia. Thus, this study was aimed to examine water storage strategies practiced by farmers for small-scale irrigation systems in East Hararghe zone, Ethiopia. Data were collected from 300 irrigation user households using an interview schedule. Collected data were analyzed using descriptive statistics and multivariate probit (MVP) model. The research findings revealed that about 62.67, 54.33, 20.33 and 17.67% of households have used borehole, shallow wells, hand-dug, and farm pond water storage practices for small-scale irrigation, respectively. The finding of the MVP model showed that the choice of using borehole water storage practices affected by education level and frequency of extension contacts. The choice of shallow wells to store water was influenced by livestock size, participation in non-farm activities, and the use of the improved seed. Furthermore, the choice of using hand-dug is affected by household size, farm size, access to training, external support, and weather information. Finally, the size of livestock ownership influenced the choice of ponds for small-scale irrigation. Therefore, various stakeholders should work to enhance the water storage capacity of the farmers by reducing the hindrances and strengthening enabling factors in the study areas.

Key words | irrigated agriculture, multivariate probit model, smallholder farming, water availability, water storage

HIGHLIGHTS

- Agricultural production of many developing countries depends on rain-fed and vulnerable to both intra-annual and inter-annual rainfall fluctuations.
- Agricultural water storage can increase local water availability during dry periods.
- Boreholes, wells, and hand-dug are the widely practiced water storage strategies in the study areas.

INTRODUCTION

Agriculture is integral to reduce poverty and ensure adequate food supplies for the growing population (Kaczan et al. 2015). However, agricultural production of many developing countries highly depends on rain-fed and vulnerable to both intra-annual and inter-annual fluctuations in rainfall (Pachauri et al. 2014). Rainfall shortage and variability result in the risk of intra-seasonal droughts. Drought aggravates a high level of food insecurity and poverty (Cochrane 2017).
Climate change is leading to an increase in the frequency of droughts thereby negatively affect the production of crops particularly during dry periods (Field et al. 2012; Shikuku et al. 2017; Astrvor 2019). These challenges can be alleviated by storing locally available water from the ground, surface, or rain when and where it is abundant (Nicol et al. 2015; Rockström & Falkenmark 2015). They argued that agricultural water storage can relatively increase agricultural and economic growth and enhance people’s well-being by supporting crops and/or livestock during dry periods.

Small-scale irrigation has vital importance to raise agricultural production and productivity of smallholder farmers to achieve food self-sufficiency and food security at the household level (Awulachew & Ayana 2011; Garcia-Bolanos et al. 2011). However, increasing the production of agricultural outputs using small-scale irrigation at the smallholder level is at its minimal stage in Ethiopia (FAO 2015). According to Belay & Bewket (2015), the estimated total of irrigable land in Ethiopia is 5.3 million hectares. Out of this, 1.6 million hectares are irrigated using rainwater harvesting and groundwater (Awulachew et al. 2010; Makombe et al. 2011). Increasing the area covered by small-scale irrigation contributes to the reliability of food supplies (FAO 2012). According to FAO (2015), about 97% of Ethiopia’s food crops are produced by rain-fed agriculture, whereas only 3% is from irrigated agriculture. While irrigation has the potential to increase cereal yields by up to 40% (Diao et al. 2010), only 8.70% of the smallholder farmers use irrigation water in Ethiopia (Sheahan & Barrett 2017). There is a huge gap between the potential and the level of irrigation applied in the country due to exhaustively unidentified factors in specific areas of the country. Hence, strengthening the options available for storing water and reducing the hindrance in irrigation activities need to be made to meet the growing food demands in Ethiopia. Agricultural water storage from underground and surface sources such as ponds, wells, borehole, and natural wetlands/streams are just among a range of possible water storage options (Hagos et al. 2012).

In areas where the amount and distribution of rainfall is insufficient to sustain crop growth and development, an alternative approach is to store water. East Hararghe zone is one of the zones affected by the disappearance and shortage of water sources, climate variability, and recurrent weather-induced shocks such as drought (Setegn et al. 2011; Tesfaye & Seifu 2016). Due to the topography and hydro-geological condition, the zone is a water resource-scarce area (Jema et al. 2010). The zone is ranked as the least among all zones of the Oromia region in terms of surface and groundwater potential (Berhane et al. 2020). It is also among the chronic food insecure area and characterized by a dense population (Mulugeta et al. 2018; Alemayehu et al. 2018). Under such variable conditions, the storage of irrigation water during the wet season can increase local water availability during dry periods. This helps to mitigate the negative effects of intra-seasonal dry spells and bridging the dry seasons and wet seasons thereby improving the agricultural productivity of smallholder farmers. Thus, water storage for small-scale irrigation is an essential tool to enhance agricultural production and productivity (Wisser et al. 2010). Therefore, this study was aimed to examine water storage strategies practiced by smallholder farmers for small-scale irrigation systems; and to identify factors that affect the choice of irrigation water storage for small-scale irrigation in East Hararghe zone, eastern Ethiopia.

**RESEARCH METHODOLOGY**

**Description of the study areas**

The study was conducted in Haramaya and Kersa districts. Both districts are found in East Hararghe zone, Oromia Regional State, eastern Ethiopia (Figure 1). The capital city of the zone, Harar, is located at 526 km from the capital city of Ethiopia, Addis Ababa. The agro-climatic characteristic of the zone is 7.67% highlands, 24.57% midland, and 67.76% lowland. The zone is bordered by Bale zone to the south, west Hararghe zone to the west, Dire Dawa administrative council to the north, and Somali regional state to the north and east. The altitude of the zone ranges from 1,200 to 3,400 metres above sea level. The annual rainfall of the area ranged from 400 to 1,200 mm and the minimum and maximum temperature is 12 and 32 ⁰C, respectively. From the total area coverage of 26,803 square kilometres (2,680,300 hectares), about 4,972 square kilometres (18.55%) are currently arable land or cultivated, about 3.48% used for grazing,
8.32% covered by forest, 5.32% used for social services, 54.13% rocky mountains or unfertile land, and 10.2% is land used for other purposes (East Hararghe Zone Agriculture Office, 2019). According to (CSA 2007), the zone has a total population of 3,490,222 persons of whom 1,772,964 were males and 1,717,258 were females. The farming system is characterized by mixed crop-livestock farming. Therefore, the crop-livestock production system is the dominant activity of the farmers in the area to generate income and improve their livelihood using both irrigation and rainfall.

Sample size and sampling techniques

Multi-stage sampling procedures were employed to select the study area and sample households. In the first stage, two districts namely Haramaya and Kersa were selected from the East Hararghe zone by considering their high potentiality in water storage capacity and irrigation practices compared to the remaining districts of the zone. In the second stage, three kebeles from each district were selected randomly. Finally, 300 households were selected randomly (Table 1).

Probability proportional to sample size methods was applied to draw the sample households from each kebeles based on the number of households in sampled kebeles.

Methods of data collection

This study was based on a cross-sectional household survey to collect quantitative data. Quantitative data were collected using interview schedule. Moreover, relevant and necessary secondary information and records for the study were collected from different published and unpublished literature such as journal articles, research conducted by others, reports of government and non-government organizations, books, and conferences.

Methods of data analysis

Quantitative continuous/dummy types of variables were analyzed using descriptive statistics such as frequency distribution, percentage, mean and standard deviation. A multivariate probit (MVP) model was applied to identify
factors that affect the choice of irrigation water storage for small-scale irrigation in eastern Ethiopia. The data analysis was conducted using Statistical Package for Social Sciences (SPSS) version 22 and STATA software.

**Econometric model for the choice of water storage strategies for small-scale irrigation**

Smallholder farmers are more likely to use a combination of water storage practices for irrigation systems to deal with water scarcity risks. This means that there is a probability of using more than one water storage practices for irrigation systems. Hence, the study applied the MVP econometric model to measure the influence of the set of independent variables on each of the different water storage practices for irrigation systems.

The dependent variable in the empirical estimation for this study is the selection of water storage practices for irrigation systems from the set of water sources such as water extracted directly from ponds or natural streams, open shallow wells, and borehole. For this study, an MVP econometric approach was characterized by a set of \( m \) dependent variables \( Y_{hpj} \) such that:

\[
Y_{hpj} = X'_{hpj} \beta_j + U_{hpj} = 1, 2, \ldots, m
\]

\[
y_{hpj} = \begin{cases} 
1 & \text{if } Y_{hpj} > 0 \\
0 & \text{otherwise} 
\end{cases}
\]

where:

\( j = 1, 2 \ldots m = \text{water storage practices for irrigation systems} \)

\( X'_{hpj} = \text{vector of independent/explanatory variables} \)

\( \beta_j = \text{vector of parameter to be estimated} \)

\( U_{hpj} = \text{error terms distributed as multivariate normal distribution with zero means} \)

\( Y_{hpj} = \text{whether or not a household using particular water storage strategies.} \)

Because the use of many water storage practices is possible, the error terms in Equation (1) are assumed to jointly follow a multivariate normal distribution with zero conditional mean and variance normalized to unity. The covariance matrix represents the unobserved correlation between the stochastic components of the \( j \)th and \( m \)th type of water storage strategies. This assumption means that Equation (2) gives a MVP model that jointly represents decisions to use particular water storage strategies.

**Operational definition of research variables and working hypothesis**

**Dependent variable**

Water storage strategies practiced by farmers for irrigation systems is the dependent variable of the study. Six water storage practices were identified. The dependent variables of the study are specified as:

\[
y_k = \begin{cases} 
1, \text{ if the household uses } k\text{th water storage} \\
0, \text{ otherwise} 
\end{cases} \quad (k = 1, 2, 3, 4, 5, 6)
\]

where \( k \) is the water storages practiced by farmers.

\( Y_{k1} \) is water storage and irrigation using ponds

\( Y_{k2} \) is water storage and irrigation using shallow wells (open)

\( Y_{k3} \) is water storage and irrigation using boreholes

**Table 1 | Selection of sample households**

| Districts | Kebeles          | Total number of households | Percentage | Sampled households |
|-----------|------------------|----------------------------|------------|-------------------|
| Haramaya  | Adale waltaha    | 1,290                      | 14.47      | 44                |
|           | Tinike           | 602                        | 6.75       | 20                |
|           | Kuro             | 1,851                      | 20.75      | 62                |
| Kersa     | Sodu             | 1,914                      | 21.46      | 64                |
|           | Haro Arba        | 1,600                      | 17.94      | 54                |
|           | Bala lange       | 1,662                      | 18.63      | 56                |
| Total     |                  | 8,919                      | 100        | 300               |
$Y_{A1}$ is water storage and irrigation using hand-dug
$Y_{A5}$ is water storage and irrigation using flood and stream diversion
$Y_{A6}$ is water storage and irrigation using water harvesting.

Operational definition of independent variables (see Table 2).

**RESULTS AND DISCUSSION**

**Demographic, socio-economic, and institutional characteristics of sample households**

Out of 300 sample households, 87.67% were male-headed households while the remaining 12.33% were female-headed households. The survey results revealed that the proportion of male-headed households who ran farms using irrigation systems exceeded that of female-headed households. This means that male farmer are engaged in water resources planning, management, and utilization more than female farmers, although women play a significant role in managing water as they have substantial involvement and stakes in both domestic and agricultural water use. The low level of women participation in water management is ascribed to several factors such as social norms confining their domestic roles, low level of education, and the gender gap in property rights. For instance, women are excluded from water rights because of the lack of rights over the land. In most of the irrigation management systems, male-headed households have more rights to use. Therefore, men represent the households while women play mainly a supporting role. As a result, women of the households usually remain invisible in water management (Khandker et al.

**Table 2 | Definitions of independent variables for the study**

| N | Variables                      | Variable type | Description and measurement                                                                 | Expected sign |
|---|--------------------------------|---------------|---------------------------------------------------------------------------------------------|---------------|
| 1 | Sex of household head (SEX)   | Dummy         | 1 if the household head is male and 0, if it is female                                     | –             |
| 2 | Age of household head (AGE)   | Continuous    | Number in years                                                                             | +/–           |
| 3 | Education status (EDULEV)     | Continuous    | Number of years of schooling (grade)                                                       | +/–           |
| 4 | Household size (HHSZ)         | Continuous    | Number of people in the household                                                          | +             |
| 5 | Experience in water harvesting (WATHE) | Continuous | Households’ experience in water harvesting in years                                          | +             |
| 6 | Perception on water storage and utilization (PERC) | Categorical | Measured as 1: Strongly disagree, 2: disagree, 3: Neutral/undecided, 4: Agree, 5: Strongly agree | +             |
| 7 | Extension contact (EXCON)     | Categorical   | Frequency of annual extension contact                                                       | +             |
| 8 | Use of improved seed (IMPS)   | Dummy         | 1, if the household used improved seeds; 0 otherwise                                        | +             |
| 9 | Training on water storage (TRAWS) | Dummy    | 1, if household head has access to water storage related training; 0 otherwise               | +             |
| 10| Experience in irrigation use (IREXP) | Continuous | Number of years since households started irrigated farming                                 | –             |
| 11| Crops grown by household head (FRCR) | Continuous | Number and frequency of crops cultivated by the household in a year                          | +             |
| 12| External support (EXSUP)      | Dummy         | 1, if the household head supported by GO/NGOs; 0 otherwise                                  | +             |
| 13| Market distance (DSMKT)       | Continuous    | Distance from household residence to the nearest market in walking hours                   | –             |
| 14| Weather information (WRINFO)  | Dummy         | 1, if household head has access to weather information; 0 otherwise                         | +             |
| 15| Farm size (FARSIZ)            | Continuous    | Size of cultivated land in hectares                                                        | –             |
| 16| Livestock holding (LIVEST)    | Continuous    | Total livestock holding in TLU                                                              | –/+           |
| 17| Off-farm/non-farm income (NFINC) | Dummy    | 1, if any member of the household is involved in off-farm/non-farm income sources; 0 otherwise | –             |
The mean age of sample household heads was 37.40 years with a standard deviation of 11.82. The mean household size was six persons per household with a standard deviation of 2.71. The mean education level of household heads in formal schooling was three years with a standard deviation of 3.62. This means that the mean level of education is grade three, while the highest level of education is grade 13 (diploma holders). Although there was peer-to-peer and adult education within the communities, this study focused on formal education and acknowledged informal education.

Socio-economic characteristics of sample households

For livestock-owned sample household heads, the mean livestock owned in a tropical livestock unit (TLU) was 2.47 with a standard deviation of 1.77. The mean farm size of household heads in hectarea was 0.49 with a standard deviation of 0.48. Out of the total sample, 12.70% of sample household heads engaged in various non-farm and/or off-farm income-generating activities such as daily work, shopping, petty trade, and rent-out motor pumps, while 87.30% of them were not engaged in any non-farm and/or off-farm activities.

Sample households institutional aspects

Survey results showed that 61% of sample households utilized different improved crop varieties. The rest (39%) of them did not utilize any improved crop seed in the previous cropping season. Regarding access to water storage-related training, the survey result showed that 14.33% of the sample households had taken training on water storage (TRAWS) techniques such as water development and management, rainwater management, searching water sources, access to and utilization of water, and the importance of using irrigation, while 85.67% of them were never trained due to inadequate access and opportunity, or absence of trainees. Regarding external support related to water storage/irrigation activities from government or non-government, only 4% of the total sample households received support, while the remaining 96% of the households did not receive any support related to water storage or irrigation development strategies.

Out of the total sample households, 43% of them accessed weather-related information, while the remaining 57% did not access weather information. Moreover, of the total sample households, 41% of them had contact with extension workers concerning water storage strategies and utilization practices while 59% have no contact with extension workers related to water storage strategies (Table 3).

The mean distance to the nearest market in a walking hour was 0.98 with a standard deviation of 0.41. The minimum and maximum years of households participation in water harvesting for small-scale irrigation was 1 and 20 years respectively with the mean 5.72 and 4.97 standard deviations. The survey result showed that the minimum and maximum years households were involved in irrigation activities were 1 and 30 years respectively with a mean of 7.49 and a standard deviation of 6.50. Regarding the types and frequency of crops cultivated by the household in a year using small-scale irrigation practices, the minimum and maximum frequency of crops produced was one and two times respectively. About 55, 40, and 5% of households produce crops two times per year, once per year, and three times per year, respectively (Table 4).

Irrigation systems practiced in the study areas

Most sample households practiced small-scale irrigation using motor pump technology. According to survey results, about 84.67, 14, and 1.33% of sample households responded that they used motor pumps, natural stream or flood diversion of water to crop field and fetching water from shallow wells.

Table 3 | Descriptive statistics of dummy or categorical variables (N = 300)

| Variables                               | Response | Frequency | Per cent |
|-----------------------------------------|----------|-----------|----------|
| Sex of household head                   | Male     | 263       | 87.67    |
|                                         | Female   | 37        | 12.33    |
| Non-farm/off-farm income                | Yes      | 38        | 12.70    |
|                                         | No       | 262       | 87.30    |
| Use of improved crop seed               | Yes      | 183       | 61.00    |
|                                         | No       | 117       | 39.00    |
| Access to training on water storage     | Yes      | 43        | 14.33    |
|                                         | No       | 257       | 85.67    |
| Received support related to water       | Yes      | 12        | 4.00     |
| storage practices                       | No       | 288       | 96.00    |
| Access to weather information           | Yes      | 129       | 43.00    |
|                                         | No       | 171       | 57.00    |
| Frequency of extension contact          | Yes      | 123       | 41.00    |
|                                         | No       | 177       | 59.00    |

Source: Field Survey, 2019.
wells respectively, as mechanisms of water application to crops lands from various water sources. However, sample households faced a set of problems during water delivery to their crop lands. For instance, the high cost of fuel for motor pumps (48.67%), the distance of the irrigation farm from water sources (24.67%), drought (14%), inadequate labour (10.33%), and stress on water sources (2.33%) confronted irrigation practices of the households.

Although different irrigation systems were practiced by sample households through different water storage practices, the majority of them practiced borehole water storage practices. About six irrigation water storage practices were identified. These included irrigation water storage using boreholes, open shallow wells, hand-dug, ponds, stream and/or flood diversions, and water harvesting. Borehole and shallow wells were the major widely practiced irrigation water storages. Of the total 300 farmers, about 62.67% and 54.33% had used borehole and shallow wells, respectively. Hand-dug and pond irrigation storages used by 20.33% and 17.67% of the sample households, respectively. The other two practices, stream and/or flood diversion and rainwater harvesting were used by only 6% and 5.67% of the sample farmers, respectively (Table 5).

### Irrigation system practiced using borehole

Out of 300 sample household heads, 62.67% of them practiced water storage practices using boreholes. The minimum and maximum depth of borehole constructed by sample households was 2 and 40 metres, respectively. The mean depth of the borehole was 19.07 metres with a standard deviation of 7.23. This indicates that sample households are digging deep holes using local farm equipment to get water for small-scale irrigation. They extract water and apply to crops using fuel-consuming motor pump. The minimum and maximum years household heads used boreholes once constructed were 0.5 and 20, respectively. The mean time households used boreholes after construction was 3.21 years with a standard deviation of 2.94. This implies that after a maximum of 20 years, the constructed borehole would be dried and the household digs another borehole to search groundwater.

### Irrigation system practiced using open shallow wells

Traditionally, farmers have built up open wells for irrigation purposes using motor pumps. Open well development is most common where groundwater is at a shallow depth and farmers dig open pits for motorized pump irrigation to improve access to groundwater for irrigation or domestic purposes (FAO 2014). Accordingly, about 54.33% of sample households used shallow wells to store water for agricultural purposes. Out of 54.33% sample households that practiced water storage using open shallow wells, 19.67, 17.33, and 16.33% of them prefer this method due to use of local labour and materials, it required little/no external support and was technically easy to construct, respectively. The mean depth of the well in metres was 14.39. Once constructed, the farmers use the well for a maximum of 5 years.

### Table 4 | Descriptive statistics of continuous variables

| Variables                        | N   | Mean | Std. Deviation |
|----------------------------------|-----|------|----------------|
| Age of household head (years)    | 300 | 37.40| 11.82          |
| Highest level of education completed (years) | 300 | 3.13 | 3.62          |
| Household size (number)          | 300 | 5.65 | 2.71           |
| Farm size (hectares)             | 295 | 0.49 | 0.48           |
| Experience in irrigation use (years) | 300 | 7.49 | 6.50           |
| Size of livestock owned (TLU)    | 276 | 2.47 | 1.77           |
| Distance to market centre (hours) | 300 | 0.98 | 0.41           |
| Experience in water harvesting (years) | 109 | 5.72 | 4.97           |
| Frequency of crops produced by household heads using irrigation (per year) | 300 | 1.65 | 0.57 |

Source: Field Survey, 2019.

### Table 5 | Irrigation water storage strategies practiced by households in the study area

| Irrigation systems               | Frequency | Percent |
|----------------------------------|-----------|---------|
| Borehole                         | 188       | 62.67   |
| Shallow wells                    | 163       | 54.33   |
| Hand-dug                         | 61        | 20.33   |
| Ponds                            | 53        | 17.67   |
| Stream (flood) diversions        | 18        | 6.00    |
| Rainwater harvesting             | 17        | 5.67    |

Source: Own computation from survey data, 2019.
Irrigation system practiced using ponds

Ponds are uncovered cavities built by individuals or communities to store water. It is often either surface runoff or groundwater used for livestock watering, domestic purposes, and small-scale irrigation (Waktola 2008; Barron 2009). On-farm ponds have a contribution for small-scale irrigation purposes at the household level (De Trinchera 2017). Out of the total sample household heads, only 7.66% of them used on-farm pond by harvesting water from rain and/flood sources. However, their success was limited by evaporation on the one hand, and safety and health risks (mosquito breeding) on the other hand. Moreover, although on-farm ponds are technically simple and constructed manually, they are vulnerable to evaporation and seepage losses. Water-harvesting technologies help to accumulate rainfall water or water from floods that can be used if rainfall shortages occur in the future. Some farmers divert the run-offs to their plots to increase soil moisture.

Factors affecting farmers’ choice of irrigation water storage practices

The MVP model was employed to identify the factors affecting farmers’ choice of irrigation water storage practices. It was estimated through the simulated maximum likelihood (SML) which was drawn 100 times. It is important to check the robustness and validity of the MVP model before embarking on the identification of factors that affect smallholder farmers’ use of different irrigation water storages.

The MVP model fits the data well as verified by the [Wald $\chi^2 (48) = 653.99, p = 0.000$]. This indicates that the null hypothesis that all the regression coefficients of all equations are simultaneously zero was rejected at the 1% significance level. Similarly, the null hypothesis that the choice of irrigation water storages are independent was rejected at the 1% significance level. The likelihood ratio test result shows that [$\chi^2 (6) = 89.2263; Prob > \chi^2 = 0.0000$]. It indicates that the null hypothesis that the choice of the four irrigation water storage practices are independent ($\rho_{21} = \rho_{31} = \rho_{41} = \rho_{32} = \rho_{42} = \rho_{43} = 0$) was rejected at the 1% significance level. Hence, the separate estimation of the choices of irrigation water storages is biased and the choices of irrigation water storages are interdependent household decisions.

Moreover, the estimated correlation matrix indicates that out of the six possible correlations, four of the correlations between water storage practices are significant at the 1% significance level. The correlation between ponds and borehole, shallow wells and hand-dug, shallow wells and borehole, hand-dug and borehole was to be significant at the 1% significance level. Accordingly, the correlation coefficients between the pairs were $-35.00$, $42.86$, $-39.88$, $-70.39$ percent, respectively. The positive and negative signs indicate that the pairs of irrigation storages were complements to each other and substitute for each other, respectively. Hence, shallow wells and hand-dug were used as a complement to each other. Ponds and boreholes, shallow wells and boreholes, hand-dug and boreholes were substituting.

As indicated in Table 6, the likelihood of choosing borehole and shallow wells stood first and second, at 61.56% and 54.19%, respectively. The likelihood of choosing hand-dug and ponds was 20.71% and 17.73%, respectively. Moreover, the joint probability of success (choosing the four irrigation systems simultaneously) was 0.23%. The joint probability of failure (not choosing all the four irrigation systems) was 4.14%.

Several variables were found to have a significant effect on the farmers’ choices of irrigation water storage practices (Table 7). Household size (HHSZ), education level (EDULEV), farm size (FARSIZ), livestock size (LIVEST), participation in non-farm/off-farm activities (NFINC), TRAWS practices, external support (EXSUP), access to weather information (WRINFO), frequency of extension contacts (EXCON), and use of improved seed (IMPS) affected farmers’ choices of irrigation water storage practices significantly. Some variables have affected different alternatives positively and negatively, while some of the variables affected different alternatives in the same direction.

The significant variables affecting farmers’ choice of irrigation water storage practices for small-scale irrigation systems are discussed subsequently.

Household size (HHSZ)

Household size has a negative and significant effect at less than 5% significance level on using hand-dug water storage practice. An increase in the household size decreases the likelihood of choosing hand-dug water storage practices.
This means that hand-dug water storage practices require less labour than other water storage strategies. The possible explanation might be that households with large size are an indicator of labour availability which enables households to engage in constructing shallow wells and boreholes. However, the studies conducted by Haji et al. (2013) and Hadush (2014) show that household size significantly and positively affected irrigation water storage practiced by households.

### Table 6 | Overall goodness of fit, correlation between choices, predicted probabilities, MVP estimates

| Variables                | Ponds | Wells | Hand-dug | Borehole |
|--------------------------|-------|-------|----------|----------|
| Predicted probability    | 0.1773| 0.5419| 0.2071   | 0.6256   |
| Joint probability (success) | 0.023 |       |          |          |
| Joint probability (failure) | 0.0414 |       |          |          |

Estimated correlation matrix

\[
\begin{pmatrix}
\rho_1 & \rho_2 & \rho_3 & \rho_4 \\
1 & \text{.1177 (.1044)} & 1 & \text{.1457(.1090)} & \text{.4286(.0970)**} & 1 \\
\rho_2 & \text{.1177 (.1044)} & 1 & \text{.4283 (.0950)**} & \text{.0401 (.0891)**} & \text{.3988 (.0891)**} & \text{.7039 (.0655)**} & 1 \\
\rho_3 & \text{.1457 (.1090)} & \text{.4283 (.0950)**} & 1 & \text{.0488 (.0862)**} & \text{.0266 (.0819)**} & \text{.0636 (.0798)**} & \text{.0398 (.0778)**} & 1 \\
\rho_4 & \text{.3988 (.0891)**} & \text{.3988 (.0891)**} & \text{.3988 (.0891)**} & 1 & \text{.0401 (.0891)**} & \text{.0266 (.0819)**} & \text{.0636 (.0798)**} & \text{.0398 (.0778)**} & 1 \\
\end{pmatrix}
\]

Likelihood ratio test of \(\rho_{21} = \rho_{31} = \rho_{41} = \rho_{22} = \rho_{32} = \rho_{42} = 0; \chi^2 (6) = 89.2263 \text{ Prob } > \chi^2 = 0.0000^{***} \)

Number of draws 100
Number of observation 300
Log pseudo likelihood

Prob > \(\chi^2 = 0.0000^{***} \)

** indicates significance at 1% significance level. Numbers in parentheses are standard errors. Source: Own analysis based on survey data, 2019.

### Table 7 | Factors affecting choice of irrigation water storages, MVP estimation results

| Outcomes Variables | Ponds | Shallow wells | Borehole | Hand-dug |
|--------------------|-------|---------------|----------|----------|
| SEX                | −0.017| 0.028         | −0.286   | 0.051    |
| AGE                | −0.014| 0.003         | 0.040    | 0.008    |
| HHSZ               | 0.008 | −0.027        | 0.048**  | −0.089** |
| EDULEV             | −0.003| −0.011        | 0.026    | −0.063** |
| FARSIZ             | 0.062 | −0.198        | 0.198    | −0.394** |
| LIVEST             | −0.261***| 0.131***    | −0.052   | 0.014    |
| NFINC              | −0.012| 0.429**       | −0.317   | 0.026    |
| TRAWS              | −0.277| 0.214         | 0.257    | −0.758** |
| EXSUP              | −0.256| 0.389         | 0.037    | 0.338    |
| WRINFO             | 0.249 | 0.180         | 0.164    | −0.425** |
| EXCON              | 0.231 | 0.418**       | 0.181    | 0.192    |
| IMPS               | 0.164 | 0.205         | 0.065    | 0.245    |
| _constant          | −0.217| 0.4599        | −0.214   | −0.577   |

\* , **, and *** imply significance at 10, 5 and 1% significance levels, respectively. RSE is Robust Standard Error. Source: Own analysis based on survey data, 2019.
They indicated that the households use the household members as a labour force and easily undertake the irrigation activity than lower household size because of labour intensive nature of small-scale irrigated farming.

**Education status (EDULEV)**

The likelihood of using hand-dug water storage practices was negatively and significantly affected by level of education, but education level has a positive relationship with the likelihood of using borehole water storage practices for small-scale irrigation at 5% level of significance. This result indicates that an increase in the level of education would decrease the probability of using hand-dug water storage strategy, but increases the likelihood of using borehole water storage strategy for small-scale irrigation. This is because educated households prefer to use boreholes using fuel-consuming motor pumps rather than extracting and applying water to crops using their hands. The plausible justification is that better-educated farmers are likely to be more informed about the benefits of storing groundwater using boreholes for small-scale irrigation systems (Kassie et al. 2011). Finally, educated farmers have a less probability of using hand-dug irrigation practices. This result is in line with Foster & Rosenzweig (2010) who found that educated households have other water storage options that enabled them to use sustainable small-scale irrigation.

**Farm size (FARSIZ)**

Farm size influenced the probability of using hand-dug water storage practices negatively and significantly at a 5% level of significance. An increase in farm size on which small-scale irrigation practiced decreases the likelihood of using hand-dug water storage practices. This is because hand-dug water storage strategy for small-scale irrigation is mostly practiced for garden irrigation systems. This showed that households with larger farm size were allocating their farm for adequate water from various sustainable sources for small-scale irrigation on the one hand and rain-fed agriculture and animal husbandry on the other hand. According to Elemo (2014), farm size is negatively influencing the irrigation practice by households.

**Livestock holding (LIVEST)**

The likelihood of using on-farm pond water storage practices for small-scale irrigation was negatively and significantly affected by TLU, but it has a positive relationship with the likelihood of using shallow wells as water storage practices for small-scale irrigation. Household heads having a large number of livestock are less likely to use on-farm ponds than households having small livestock sizes. A rise in livestock asset increases the probability of not using on-farm ponds to store water for small-scale irrigation. However, households having large livestock invest in shallow well water storing for small-scale irrigation. This shows a positive relationship between using shallow wells and livestock holding. A possible explanation is that livestock asset owners can purchase well constructing equipment and geomembranes instead of using ponds. Contrary to this finding, Hadush (2014) found that the total livestock owned by the households showed a positive significant effect on the irrigation practices. Farmers with a higher TLU were found to have a higher probability of being engaged in irrigation practice more than those with lower values.

**Off-farm/non-farm income (NFINC)**

Engagement in non-farm/off-farm income-generating influenced the choice of using a shallow wells water storage strategy positively and significantly. Participation of households in non-farm/off-farm income-generating activities increased the likelihood of choosing shallow wells for small-scale irrigation. This might be because the household head or household members engaged in non-farm/off-farm income-generating activities can finance the purchase of technologies and types of equipment used to construct wells for small-scale irrigation. This indicates that a household engaged in NFINC-generating activities were found to participate in irrigation water storage practices more than those not engaged in non-farm activities. Beyan et al. (2014) and Hadush (2014) showed that the positive relationship between NFINC-generating activities and irrigation practice by households was because the income from non-farm activities was used to cover the water storage and irrigation costs such as inputs and pieces of equipment required.
Training on water storage (TRAWS)

Access to water storage training was negatively and significantly related to hand-dug water storage practices. This indicates that households who took training are less likely to choose to use hand-dug water storage practices for small-scale irrigation. The reason might be that trained households prefer to use other adequate and sustainable water storage practices for small-scale irrigation compared with not trained households. However, Abiyu et al. (2015) and Nhundu et al. (2015) found that access to TRAWS for irrigation practices positively and significantly influences the engagement in irrigation practice. This implies that farmers who attended more water storage training were found with a higher probability of engagement in irrigation practice than their counterparts.

External support (EXSUP)

Access to external support on water storage strategies for small-scale irrigation has a negative and significant effect on households’ choices of hand-dug water storage strategy. Access to external support would decrease the probability of choosing hand-dug water storage practices for small-scale irrigation. This means that households received external support in kind or cash from various government and non-government organizations to invest in other options of water storage practices such as borehole and well construction than households who did not receive the support. Since the cost of irrigation equipment has increased beyond what most farmers can afford, the support of government and non-government organizations enhances the farmers’ involvement in irrigation development activities (Abiyu et al. 2015).

Weather information (WRINFO)

Farmers obtain weather-related information through demonstrations, attending field days or listening to agricultural programmes on the radio. Thus, availability and accessibility of weather information enhanced the preparation and adaptation of farmers to climate change. Several studies have found positive and significant relationships between access to weather information and adoption of climate smart agriculture technologies. For example, the study conducted by Gecho (2005) and Hadush (2014) indicated that ownership of a radio had positive influence on adoption of agricultural technologies. Contrary to this, access to weather information has a negative and significant effect on households’ choice of hand-dug water storage practices. Access to weather information would decrease the probability of choosing a hand-dug water storage strategy for small-scale irrigation. This indicates that households’ access to adequate weather information focused on various water storage strategies rather than using hand-dug.

Extension contact (EXCON)

The likelihood of choosing shallow wells and hand-dug water storage practices was affected positively and significantly by the frequency of extension contact on water storage practices and negatively affected by using borehole storage practices for small-scale irrigation. This means that frequent contact of extension agents with households increases the likelihood of using shallow wells and hand-dug water storage practices and decreases the likelihood of choosing borehole water storage practices. Households with close contact to extension agents prefer practices of shallow wells and hand-dug water storage practices for small-scale irrigation than other strategies. This might be because using shallow wells and hand-dug water storage practices are technically simple and locally available to use relative to other water storage practices for small-scale irrigation. In line with this finding, Sidibé (2005) and Nhundu et al. 2015 pointed out that farmers with frequent contact with extension workers can easily access information about water storage practices for small-scale irrigation, and can upgrade their know-how on irrigation development.

Use of improved seed (IMPS)

Irrigation requires the use of modern inputs such as IMPS and fertilizers, which further enhance agricultural productivity (Diao et al. 2010; Gebregziabher & Holden 2011). Empirical literature shows that modern inputs are used more in irrigated farming than rain-fed farming and as a result productivity is higher in the former. For instance, Gollin et al. (2005)
underlined that the green revolution had the highest impact on irrigated cereals. However, the MVP model results revealed that the use of IMPS has a negative and significant effect on households’ choice of shallow wells water storage practices. Using IMPS would decrease the probability of choosing shallow wells for small-scale irrigation. The plausible explanation is that households who use shallow wells water storage practices for small-scale irrigation are less likely to use IMPS than those who choose other water storage practices.

**CONCLUSIONS**

This study examined water storage strategies practiced by smallholder farmers for small-scale irrigation systems. It identified some of the major factors that affect irrigation water storage for small-scale irrigation in East Hararghe zone, eastern Ethiopia. Demographic, socio-economic, and institutional factors influencing water storage strategies for small-scale irrigation activities were analyzed using an MVP model. Out of the 12 explanatory variables included in the model, ten of them were found to have a significant effect on farmers’ choice of irrigation water storage practices. Some variables have affected different water storage alternatives positively and negatively, while some of the variables affected different alternatives in the same direction. Therefore, there is a need for various stakeholders to take part in enhancing the water storage capacity of farmers by reducing hindrances and strengthening enabling factors in the study areas.

**DATA AVAILABILITY STATEMENT**

All relevant data are included in the paper or its Supplementary Information.

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