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Impact of irrigation on welfare and vulnerability to poverty in South African farming households

Adetoso Adebiyi Adetoro[a,*], Mjabuliseni Simon Cloapas Ngidi[b], Gideon Danso-Abbeam[c,e], Temitope Oluwaseun Ojo[d,e], Abiodun A. Ogundeji[e]

[a] *African Centre for Food Security, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa*
[b] *Department of Agricultural Extension and Rural Resource Management, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville 3209, Pietermaritzburg, South Africa*
[c] *Department of Agribusiness, University for Development Studies, Tamale, Ghana*
[d] *Department of Agricultural Economics, Obafemi Awolowo University, Ile-Ife, Nigeria*
[e] *Disaster Management Training and Education Centre for Africa, University of the Free State, PO Box / Posbus 339, Bloemfontein 9300, South Africa*

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ABSTRACT

Many empirical studies have documented the role of farm management practices such as irrigation in reducing poverty and improving household well-being. Few studies, however, have looked at the impact of irrigation farming on poverty vulnerability and the welfare of rural farming household. This study examined the factors that influence farmers' participation in irrigation farming, as well as how it affects farmers' food consumption expenditure per capita (proxy for welfare), poverty gap index, poverty severity and poverty vulnerability. The study's data was collected from farming households in the northern and coastal parts of the Eastern province of South Africa. The endogenous switching regression (ESR) model was employed in the study to account for selection bias that could be caused by both observed and unobserved household factors. The empirical result shows that gender, household size, educational attainment, crop diversification, and market outlet among others influenced farmers' decision to practice irrigation farming. Farmers engaging in irrigation farming boosted their food consumption per capita by 44%, while non-participants would have increased their consumption expenditure per capita by 23% if they had participated. Moreover, participating farmers reduced their poverty gap index by 20% and poverty severity by 22%, whereas non-participating farmers could have reduced their poverty gap index and poverty severity by 5% and 17%, respectively had they engaged in irrigation farming. Participation in irrigation farming also reduced poverty vulnerability by 25%, while non-participants may have reduced poverty vulnerability by 3%. The findings suggest that enhancing farmers' access to irrigation is crucial to meeting the Sustainable Development Goals (SDGs), which aim to eradicate poverty in all its manifestations everywhere.

* Corresponding author.
E-mail address: toshorr@gmail.com (A.A. Adetoro).

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Introduction

Poverty and hunger continue to be the most pressing issues facing the development of many nations around the world, particularly in the less developed regions such as Sub-Saharan Africa (SSA). SSA remains the world's most food-insecure region, with nearly a quarter of the population (more than 230 million people), suffering from malnutrition ([21,55]). As a global goal, the 2030 agenda for Sustainable Development has recognized the significant consequences of rising food poverty which requires urgent attention. According to the World Bank [59], poverty is defined as a multifaceted notion that includes low income and consumption, poor educational accomplishment, poor health and nutritional results, a lack of basic services, and a hazardous living environment. To categorize households based on the different levels of poverty, a poverty line of US$1.90 per day is used as an indicator of extreme poverty [59].

Many of the extremely poor households live in rural areas and rely on agricultural production for a living [23]. To improve long-term food security and alleviate poverty, agricultural production systems are expected to be more productive and reduce output variability in the face of climate extremes such as land degradation. Farmers' productivity stability is linked to the adoption of a resilient food production system that can withstand disruptive events [46]. Irrigated farming has been identified as a viable means of increasing agricultural productivity, farmers' revenue, and household consumption as a mitigation strategy [46]. Irrigation aids in the stabilization of food production by shielding it from the unpredictability of rainfall. Irrigation farming systems are a critical policy strategy for eradicating poverty and increasing food security [19]. In addition, irrigation participation is especially crucial in import-dependent developing countries, where agriculture employs the bulk of the population. Irrigation projects and existing schemes, despite their importance in economic growth and investment, are still underperforming in terms of realizing their full potential [32], particularly in a semi-arid country like South Africa.

In South Africa, farmers' participation in irrigation farming is generally low, with smallholder irrigation land area accounting for around 0.1 million hectares (8%) of the aggregate irrigated land [12,53]. Despite the importance of smallholder farmers to the South African economic development as they possess potential for improving the rural livelihoods, farmers participating in different irrigation schemes perform below suboptimal levels [9,19,38,53]. Water management, financing access, market access, poor infrastructure maintenance, and the farmers' age have been found to contribute to low participation in irrigation farming in many developing countries [57,58]. Christian et al. [9] observed that irrigation participation in South Africa is influenced by farmers' age, family size, financial availability, extension contact, and membership of farmer groups. While factors determining participation in irrigation farming has gained some attention in South Africa, the impact of irrigation participation on household welfare, poverty and vulnerability to poverty has been inadequately explored. As a result, any untapped potential to enhance household welfare and reduce household poverty level and vulnerability to poverty through smallholder irrigation participation in South Africa is critical. Many pieces of literature [1,26,32,40,47,66] have reported that participation in irrigation farming could serve as a way to create new job opportunities, both on and off the farm, and boost rural incomes, improve livelihoods, improve food security and alleviate poverty, through improvement in farm productivity. However, while there is evidence that irrigation development reduces poverty in several countries, the impact is determined by farm, irrigated technology and household variables. For the reasons stated above, it is vital to investigate whether irrigation users are significantly better off than non-users in terms of not only poverty status but poverty incidence, depth, and severity, as well as the impact irrigation has on consumption levels. Moreover, plethora of empirical studies on poverty has one major shortcoming: the failure to estimate treatment (use of irrigation) on vulnerability to poverty. It is critical to recognize the differences between poverty and vulnerability. The former is more concerned with one's immediate well-being, whilst the latter is concerned with one's long-term well-being. Thus, assessing poverty without considering vulnerability to poverty may result in insufficient information for future agricultural-related program design and implementation. Thus, there is little empirical literature on the impact of irrigation participation on an extended outcome such as household welfare and household poverty, as well as vulnerability to poverty. As a consequence, the study hypothesized that smallholder farmers who participate in irrigation farming have higher consumption expenditure per capita, a lower poverty level, and are less vulnerable to poverty than non-participants.

This study brings out novelty in poverty-related studies in the following ways. First, we estimate the contribution of irrigation usage on not only poverty reduction but the incidence and severity of poverty as well as the vulnerability to poverty among farming households in rural South Africa. Knowing who is poor, the intensity of poverty and who is at risk of becoming poor is critical to inform farm-level policy initiatives and executions. Second, the study followed rigorous technique used by World Bank [59] to measure poverty. Third, the study takes into consideration both observed and unobservable factors of irrigation participation through the use of the endogenous switching regression to account for selection bias and the potential endogeneity of participation in irrigation farming.

Prior researches in the country are sparse in this regard, making it difficult to make conclusions. Changing sociocultural, political, and economic factors entail the need for up-to-date research findings on which to base the formulation and implementation of various programs to improve livelihoods. Through the provision of new empirical evidence, the study thus contributes to the efforts of government, international development organizations (e.g., FAO, International Water and Management Institute, etc.), and other stakeholders to strengthen and better understand the impact of irrigation sector reforms on poverty reduction and household welfare.

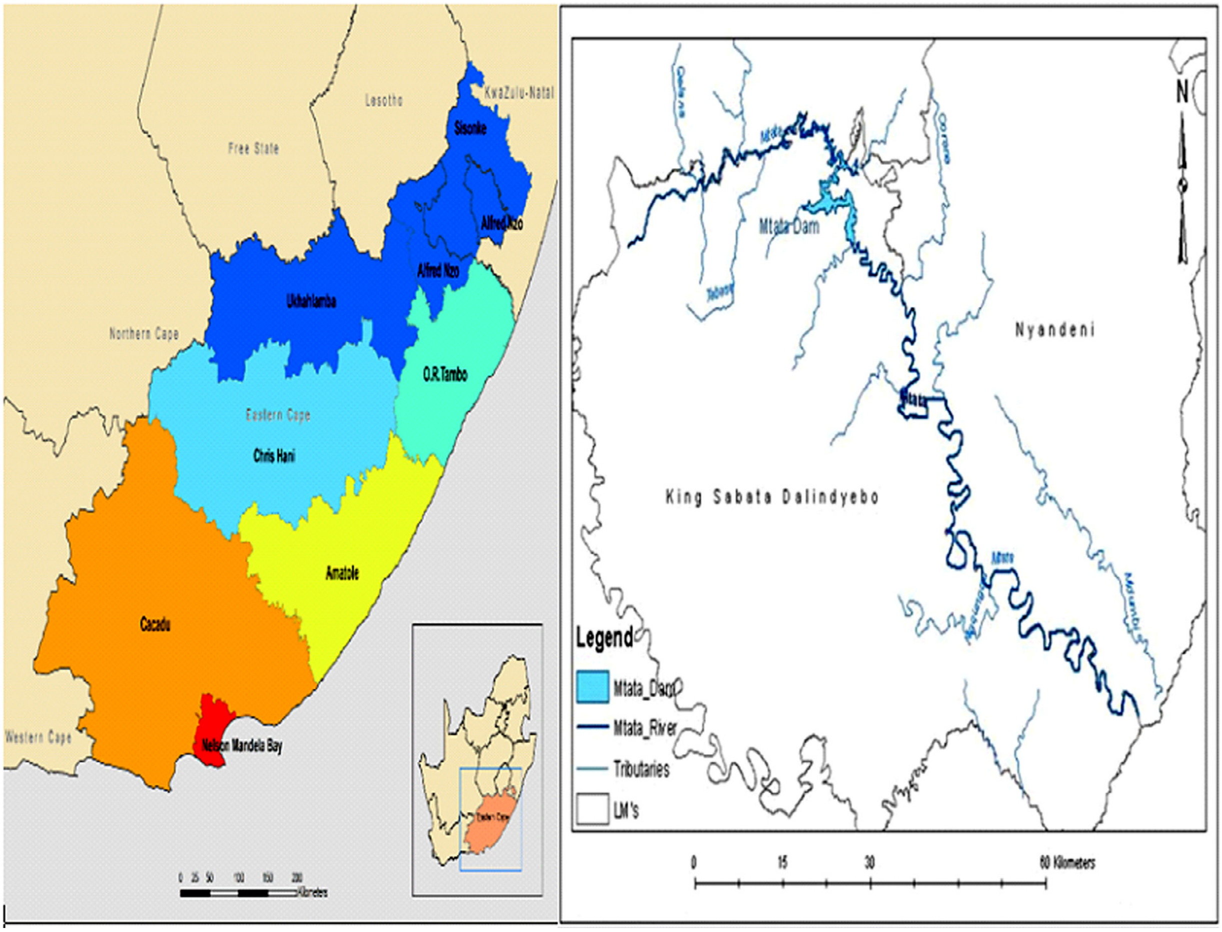

Fig. 1. Map of South Africa showing the district under which the selected local municipalities are located.

Methodology

Description of the study area and data collection

This study was conducted in the King Sabata Dalinyebo and Nyandeni local municipalities which fall under the OR Tambo District Municipality, representing the local municipalities in the Mthatha River basin in Eastern Cape province (Fig. 1). The district is functionally rural, characterized by low educational levels and predominantly an agricultural producing area [18]. The Mthatha River provides drinking and irrigation water to the residents in the catchment area. The Mthatha River catchment has a dimension of approximately 100 km long and 50 km wide, with a total area of 5 520 km^3. The Mthatha River, which is 250 km long and has two big tributaries, flows north of Coffee Bay (Mankosi village). The Mthatha and Corana Dam, both on the Mthatha River's Corana branch, are major water storage reservoirs in the Mthatha basin. The Mthatha Dam has an 886 km catchment area and can store up to 254 million cubic meters of water while producing 14.5 million cubics of water per year [25].

A multi-stage sampling technique was employed for data collection. A purposively sampling technique was used to divide the catchment into four regions in relation to the source of the Mthatha River. These are the upper region, peri-township region, the lower region and the coastal region. In each of the areas, ten villages were chosen at random, of which 11 respondents were randomly chosen in each village based on their desire to participate in the survey. In total, 440 households were interviewed but only 400 were considered credible for analysis due to some uncompleted questionnaires.

The study employed a quantitative method for the collection of data using a survey questionnaire. The survey questionnaire was prepared in English and then translated to a local language (isiXhosa), as it is assumed that people feel more at ease speaking to others in their language, which improves the accuracy of information obtained and survey's dependability. Following Dubbert [17], the quantitative method was used to compare responses between the participants and non-participants of irrigation farming because all respondents were asked identical questions in the same order to allow for significant comparison. The important sections of the questionnaire focus on respondents' use of irrigation, farm activities, source of finance, water access and challenges associated with household food security. The questionnaire's other major component was designed to find out about households' demographic profiles and consumption patterns.

Conceptual framework

This section presents the concepts employed to estimate the impact of irrigation participation on rural households' welfare outcomes. To achieve the objectives of this study, we assumed that the farm households make a binary decision on whether to participate or not participate in irrigation farming, based on certain factors such as their socioeconomic, farm-specific and other institutional characteristics. The farmers decide by comparing the expected utility from participating (U_i^P) and the expected utility from not participating (U_i^{NP}). Farmers' decisions are skewed toward participating in irrigation farming if the predicted outcome is favourable:$P_i^* = U_i^P - U_i^{NP} > 0$. This indicates that the benefit of participating in irrigation farming is greater than the benefits of not participating in irrigation farming. However, P_i^* is a latent variable, therefore it cannot be observed. It is, thus specified as a function of farmers' demographic characteristics, institutional factors, farmer assets and farmer-specific factors as follows:

$$P_i^* = \beta D_i + \alpha A_i + \partial M_i + \Phi I_i + \varepsilon_i, P_i^* = \begin{cases} 1 if P_i^* > 0 \\ 0 if P_i^* < 0 \end{cases} \tag{1}$$

where P_i is the binary parameter given the value of 1 if a farmer is a participant of irrigation farming and 0 if otherwise. The explanatory variables that are likely to influence participation are D_i which represent a vector of farmers' demographic characteristics such as age, household size, age, gender, education and farming (which represent the primary occupation).A_i is the farmers' assets such as livestock owned, non-farm income, and remittances, M_i represent other explanatory variables such as water right, water access and market outlet whileI_i representing the social network such as farmer association. Lastly,ε_i is the error term with mean zero and variance σ^2. The selection of the independent variables followed empirical evidence of relevant participation and adoption literature [13,17,45].

As hypothesized, participation in irrigation farming is expected to improve farmers' welfare (measured based on household consumption per capita) and poverty levels reduction, which are the outcome variables, the irrigation participation decision is linked to the outcomes using a linear function, expressed as:

$$Z_i^{cp} = \chi P_i + \beta D_i + \alpha A_i + \partial M_i + \lambda I_i + \mu_i \tag{2}$$

where Z_i^{cp} is the vector of welfare and poverty outcome variables, P_i is the participation indicator variable (1 if a household participates, 0 if otherwise), χ is the participation parameter to be estimated and μ_i is the error term. Following Danso–Abbeam et al. [13], Martey et al. [64] and Sinyolo et al. [62], the direction of the participation parameter χ would be rightly estimated provided that farmers are randomly assigned to treatment and non-treated groups. The analysis of participation choices, especially using cross-sectional data with non-randomized treatment groups tends to have issues of endogeneity and sample selection bias. The participation status of farmers is described as endogenous when there is a correlation between the error term of the participation equation (i.e., Eq. (1)) and the error term of the outcome equation (i.e., Eq. (2)). Policy-relevant variables such as extension contacts and off-farm work engagement are possible endogenous variables that are reported to explain farmers' participation in irrigation farming [50]. Failure to address the issues of endogeneity and selection bias leads to underestimation or overestimation of the true impact of irrigation participation on welfare and poverty indicators. Hence, we employed the ESR to estimate the impact of irrigation participation on welfare and poverty outcomes. This approach was preferred because it addresses both the observed and unobserved heterogeneity. In addition, the ESR model was used because it has the capability to control for every possible bias that has the potential to affect the outcomes [44]. Similar to our study, the ESR has been used in many previous empirical studies [45,50].

Empirical approach: ESR

As stated earlier, we used ESR, which has been applied in many impacts evaluation studies. The ESR uses outcome variables, where farmers are faced with two different regimes, namely: participation in irrigation farming (Regime 1) and non-participation in irrigation farming (Regime 2). The two regimes are expressed with the following equations:

$$P_i^* = \beta D_i + \alpha A_i + \partial M_i + \Phi I_i + \lambda I_i + \mu_i \tag{3}$$

$$\textbf{Regime1}: Z_{1i}^{cp} = \beta D_{1i} + \alpha A_{1i} + \partial M_{1i} + \Phi I_{1i} + \varepsilon_{1i}, \textbf{if} P_i = 1 \tag{4a}$$

$$\textbf{Regime2}: \mathbf{Z_{2i}^{cp}} = \beta \mathbf{D_{2i}} + \alpha \mathbf{A_{2i}} + \partial \mathbf{M_{2i}} + \mathbf{\Phi I_{2i}} + \varepsilon_{\mathbf{2i}}, \mathbf{if P_i = 0} \tag{4b}$$

where Z_i represent the outcome variables (consumption per capita and poverty levels). D_i, A_i, M_i and I_i are the exogenous various expected to influence the outcome variables. Hence, Eq. (4a) and (4b) link the exogenous variables to the outcome variables in each of the regimes. The parameter to be estimated are β, α, ∂ and Φ for the vectors D_i, A_i, M_i and I_i, respectively. The μ_i and ε_i are the stochastic disturbances with zero mean and variances σ_μ^2 and σ_ε^2. We specified the covariance as:

$$Cov(\varepsilon_1, \varepsilon_2, \mu_3) = \begin{pmatrix} \sigma^2{}_{\varepsilon 1} & . & \sigma_{\varepsilon 1\mu} \\ . & \sigma^2{}_{\varepsilon 2} & \sigma_{\varepsilon 2\mu} \\ . & . & \sigma^2{}_{\mu} \end{pmatrix} \tag{5}$$

where σ^2 represent the variance of the disturbance term in Eq. (1). According to Greene [24], the coefficient σ^2 is assumed to be equal to 1 because it can only be approximated up to a scale factor.$\sigma^2{}_{\varepsilon 1}$ and $\sigma^2{}_{\varepsilon 2}$ denote the terms of the variance in the welfare outcome variables in Eq. (4a) and (4b) while $\sigma_{\varepsilon 1\mu}$ and $\sigma_{\varepsilon 2\mu}$ represent the covariance of μ_i, ε_{1i} and ε_{2i}. The covariance between ε_{1i} and ε_{2i} is difficult to define because Z_{1i}^{cp} and Z_{2i}^{cp} are unobservable at the same time [31].

One hurdle that is critical in impact evaluation using instrumental variable (IV) procedures such as ESR is the identification of the selection equation. For identification, four instruments were selected, namely; farm-based organization, credit support from the government, land leased and land communally. These four variables are hypothesized to be correlated with the participation model but not the error terms of Eq. (4a) and (4b). We followed relevant empirical studies [13,27] where the four variables were used as selection instruments. In addition, a simple falsification test recommended by Di Falco (2011) was employed, and applied in empirical studies (e.g., [13,34,64]) to statistically ascertain the validity of the four instruments.

To accurately measure the impact of participation in irrigation farming on the outcome variables, we followed the framework applied by many impact studies such as Mmbando et al. [34]; Sinyolo [62], Martey et al. [64], Bello et al. [68], Danso–Abbeam et al. [13], among others, for the treated and the control group. This was performed by estimating the average treatment effect on the treated (ATT) and average treatment effect on the untreated (ATU) by comparing the expected outcome values in the actual and counterfactual scenarios. The condition expectations of the participation decision are estimated from the ESR as follows:

Participants with participation (observed in the sample) – actual scenario

$$E(Z_{1i}^{cp}/P_i = 1) = \beta_1 D_{1i} + \alpha_1 A_{1i} + \partial_1 M_{1i} + \Phi_1 I_{1i} + \sigma_{\varepsilon 1\mu}\lambda_{1i} \tag{6a}$$

Non-participants without participation (observed in the sample) – actual scenario

$$E(Z_{2i}^{cp}/P_i = 0) = \beta_2 D_{2i} + \alpha_2 A_{2i} + \partial_2 M_{2i} + \Phi_2 I_{2i} + \sigma_{\varepsilon 2\mu}\lambda_{2i} \tag{6b}$$

Participants had they decided not to participate (not observed) – counterfactual scenario

$$E(Z_{2i}^{cp}/P_i = 1) = \beta_2 D_{2i} + \alpha_2 A_{2i} + \partial_2 M_{2i} + \Phi_2 I_{2i} + \sigma_{\varepsilon 2\mu}\lambda_{1i} \tag{6c}$$

Non-participants had they decided to participate (not observed) – counterfactual scenario

$$E(Z_{1i}^{cp}/P_i = 0) = \beta D_{1i} + \alpha A_{1i} + \partial M_{1i} + \Phi I_{1i} + \sigma_{\varepsilon 1\mu}\lambda_{2i} \tag{6d}$$

The above equations show the actual expectations observed by the researcher from the sample are Eqn. (6a) and (6b), and the counterfactual expected outcomes are Eq. (6c) and (6d).

The predicted change in the outcome variables of the participants, which is the effect of the treated (participants), is called ATT. If the attributes of participants and non-participants have equal advantages, or participants have similar characteristics to non-participants, then ATT indicates the mean of the participant's outcome. The ATT can be estimated as the difference between Eq. (6a) and (6c):

$$ATT = Equation(6a) - Equation(6c) = E(Z_{1i}^{cp}/P_i = 1) - E(Z_{2i}^{cp}/P_i = 1) \tag{7}$$

Similarly, the effects of the treatment on the untreated termed as ATU is expected to change the welfare and poverty outcomes of the non-participants. In other words, the ATU can be described as the expected change in the consumption per capita and poverty levels of the non-participants if the characteristics of non-participants had the same advantage as the participants or if the non-participants had the same characteristics as participants. The ATU is specified as the difference between Eq. (6b) and (6d):

$$ATU = Equation(6b) - Equation(6d) = E(Z_{2i}^{cp}/P_i = 0) - E(Z_{1i}^{cp}/P_i = 0) \tag{8}$$

Estimation of poverty and vulnerability to poverty

This study used the Foster, Greer and Thorbecke (FGT) poverty measures [22] to estimate the poverty gap, poverty gap index and poverty severity, while the vulnerability estimation followed the study of Chaudhuri et al. [63]. The incidence of poverty (headcount index) is a metric that gauges the percentage of the population living below the poverty line. For this study, we used the World Bank poverty line of $1.91 per day [59]. On the other side, the poverty depth index (poverty gap) measures the household distance away from the poverty line. The poverty severity index also termed as the poverty gap square considers both the poverty gap and the disparity between the poor. This means that higher weight is assigned to the households that are far from the set poverty line. For this study, we used food consumption per capita expenditure of households for the measurement of poverty as it contains information, material deprivation and work intensity [56]. The FGT poverty index was estimated as:

$$P_\alpha = \frac{1}{n}\sum_{i=1}^{q}\left[\frac{(z-Y_i)}{z}\right]^\alpha \tag{9}$$

where P_α represent the FGT poverty index, n denote the household sample size, Y_i is the consumption per capita expenditure for each adult for i^{th} household, z is the poverty line, q denotes the number of households below the poverty line while α is the parameter for poverty aversion (that is, the level to which a poverty metric is sensitive to inequality among impoverished households). A poverty aversion takes the 0, 1 or 2 values, with the values explaining the level of sensitivity of poverty measure to inequality among the poor.

Following the World Bank approach [59] for the estimation of the poverty gap index, we estimated the total number of households who fall below the poverty line and express it as the percentage of the poverty line. The poverty gap function G_i was first generated (in Eq. (10)) and then the poverty gap index was calculated in Eq. (11) as:

$$G_i = (z - x_i), (\mathbf{WithG_i = 0whenxi > z}) \tag{10}$$

Where z is the poverty line and x_i represents the value of consumption expenditure per capita for the ith person's household. Next, we calculate the poverty gap using Eq. (11):

$$P_{gidx} = \tfrac{1}{n}\sum_{i=1}^{n}\frac{G_i}{z} \tag{11}$$

Where P_{gidx} represent the poverty gap index, G_i denotes the index function and z is the poverty line.

The poverty severity index was calculated by squaring the poverty gap index, which takes into account the inequality among the poor households given the assigned weights. Therefore, the poverty severity P_{svidx} is calculated as:

$$P_{svidx} = \tfrac{1}{n}\sum_{i=1}^{n}\left(\frac{G_i}{z}\right)^2 \tag{12}$$

For the estimation of household vulnerability to poverty, we followed the approach of Chaudhuri et al. [63]. We define poverty vulnerability as a household's likelihood of falling into poverty at least once in the next few years. Then we calculate the probability that a farm household *hd* will be vulnerable to become poor at a time *t* as:

$$V_{hd,t} = prob\left(InC^{f}_{hd,t+i} < Inz\right) \tag{13}$$

where $V_{hd,t}$ represent the household *hd* vulnerability to poverty at time t. and $C^{f}_{hd,t+i}$ denotes the food consumption of farm household *hd* at a time *t+i*. The *Inz* represent the natural log of the poverty line of farm household *hd*. Several observable and unobservable home variables influence a farm household's food consumption expenditure. The household food consumption expense expression is based on the assumption that the relationship is linear, and the influencing factors are estimated as:

$$InC^{f}_{hd} = \vartheta X_{ihd} + \varepsilon_{hd} \tag{14}$$

where X_{ihd} is the vector of the farm household's participation in irrigation farming and other observable individual features, ϑ is the vector of variables of interest, and ε is the error term that is associated with the idiosyncratic attributes that are normally distributed with the mean zero and constant variance. By incorporating the coefficient estimates stated in Eq. (14), we estimated the vulnerability to poverty as:

$$\hat{V}_{hd,t} = prob(InC^{f}_{hd,t+1} < Inz|X_{hd,t}) = \Psi(Inz - \hat{\vartheta}\hat{\gamma}X_{hd,t}) \tag{15}$$

Where $\hat{V}_{hd,t}$ represent the estimated vulnerability to poverty (likelihood of a farm household falling below the poverty line in subsequent years), which depends on an individual's participation in irrigation farming and other attributes. The Ψ denote the cumulative distribution function of the Gaussian distribution and $\hat{\gamma}$ represent the estimated standard error from Eq. (14).

To account for the possibility of heteroskedasticity issue often caused by violation assumption of the constant variance, Chaudhuri et al. [63] proposed a linear linkage of deviation of food consumption function to individual attributes which is denoted as:

$$\gamma^2_{\varepsilon,hd} = \sigma X_{hd} + \varpi_{hd} \tag{16a}$$

Given that participation in irrigation farming could be endogenous, it is important to correct the issue of endogeneity using a relevant instrument. For this study, we used irrigation participation as the instrument variable and the recommended standard three-stage Feasible Generalized Least Square (FGLS) method to correct for heteroskedasticity [4]. To achieve this, we estimated Eq. (14) using the Ordinary Least Squares (OLS) and then used the residuals stated in estimate Eq. (16).

$$\hat{\gamma}^2_{OLS,hd} = \hat{\sigma} X_{hd} - \hat{\varpi}_{hd} \tag{16b}$$

where $\hat{\varpi}_{hd}$ is the stochastic error term.

Using the FGLS estimate, we transformed Eq. (14) so as to derive Eq. (17a) and (17b), expressed as follows:

$$\hat{\gamma}_{\varepsilon,hd} = \sqrt{X_{hd}\hat{\sigma}_{FGLS}} \tag{17a}$$

$$\frac{InC^f_{hd}}{\hat{\gamma}_{\varepsilon,hd}} = \vartheta \left[\frac{X_{hd}}{\hat{\gamma}_{\varepsilon,hd}} \right] + \frac{\varepsilon_{hd}}{\hat{\gamma}_{\varepsilon,hd}} \tag{17b}$$

Eq. (17b) was derived by dividing Eq. (13) by the standard error obtained in Eq. (17a). The estimate ϑ is an asymptotically reliable and efficient coefficient. Subsequently, we estimated the projected log of food consumption per capita expenditure and its deviation by employing ϑ_{FGLS} and $\hat{\sigma}_{FGLS}$ expressed in Eq. (18a) and (18b):

$$E\left\{ \left[\frac{In\hat{C}^f_{hd}}{X_{hd}} \right] \right\} = \hat{\vartheta} X_{hd} \tag{18a}$$

$$E\left\{ \left[\frac{In\hat{C}^f_{hd}}{X_{hd}} \right] \right\} = \hat{\gamma}^2_{hd} = \hat{\sigma} X_{hd} \tag{18b}$$

Lastly, we assumed that the log of food consumption per capital expenditure follows a normal distribution and the vulnerability to poverty was estimated as:

$$\hat{V}_{hd,t} = prob\left(InC^f_{hd,t+1} < Inz|X_{hd,t}\right) = \Psi \left\{ \frac{Inz - \hat{\vartheta}_{FGLS}X_{hd}}{\sqrt{\hat{\sigma}_{FGLS}X_{hd}}} \right\} \tag{19}$$

We choose a vulnerability poverty threshold of 0.5, as recommended by Dey [15] because it is more appropriate. As a result, farm households with a 50% or higher chance of slipping into poverty in the future are considered vulnerable to poverty.

Results and discussion

Definition of variables and summary statistics

Table 1 presents the descriptive statistics and statistical test of differences in characteristics for participants and non-participants of irrigation farming. The proportion of male-headed households in the participant and non-participant groups is 0.70 and 0.65, respectively. Farmers had an average age of 45 years, which is within the age range of the working population. The average age of participant and non-participant households was 46 and 45 years, respectively. This is similar to the average age of 52 years for Eastern Cape province found in the study of Akinyemi and Mushunje [3].

As indicated in Table 1, the household size for the participants of irrigation farming is lower than the non-participants. A higher proportion of the participants of irrigation farming experienced flooded farms over the last 12 months preceding the survey compared with the non-irrigation participants. Furthermore, the statistics show that more respondents under the participants of irrigation farming category obtained income from livestock sales and also incur lesser expenses on education. This is similar to the study of Mwangi and Crewett [39] who found that participation in irrigation farming was driven by years of education of the farmers. Participants in irrigation farming receive more financial support through remittances than the non-participants, with many of the participants preferring to engage in seasonal farming. The majority of the farmers who practiced crop diversification are irrigation participants, with most of the participants having more education years than the non-participants in the study area. The statistics result shows that leased and communal land were important variables for assessing irrigation farming participation, given that land tenure system, especially the communal land, prohibits the purchase/sale in South Africa, for instance, the case of KwaZulu-Natal [51,53].

The treatment variable used in the study was irrigation farming and the result shows that about 45% of the households participated in irrigation farming while the remainder represents the non-participants.

Table 1
Descriptive statistics of the respondents.

Explanatory variable	Description	Participant (n = 180)	Non-participant (n = 220)	Mean difference
Gender	1 if household head is male, 0 if female	0.697	0.651	0.050
Household Age	Age of household head (years)	45.740	44.950	0.794
Household size	Number of persons living in the household	3.156	3.368	-0.213
Flooded farm plot	1 if household experience flood on farm plot, 0 otherwise	0.350	0.250	0.100
Income from livestock production	1 if income was generated from livestock sales, 0 otherwise.	0.756	0.714	-0.042
Education expenses	1 if household spend on education, 0 otherwise	0.878	0.886	0.009
Remittances	1 if household received remittances, 0 otherwise	0.272	0.15	-0.122
Non-farm activity	1 if household engaged in other non-farm activity, 0 otherwise	0.414	0.414	-0.031
Engage in seasonal farming	1 if household practice seasonal farming, 0 if otherwise	0.606	0.505	-0.101
Market outlet	1 if household has access to various market outlets, 0 otherwise	3.183	2.773	0.411
Crop diversification	The number of different food crop types cultivated by the households.	5.339	5.005	0.334
Education (years)	Years of education of household head	6.480	5.701	0.779
Rented land	1 if household rented a land for farming, 0 otherwise	0.289	0.241	-0.048
Owned land	1 if household own land for farming through inheritance, 0 otherwise	0.094	0.086	0.008
Communal land	1 if household farm on a communal land, 0 otherwise	0.033	0.114	0.080
Leased land	1 if household use a leased land for farming, 0 otherwise	0.089	0.041	0.048
Road accessibility	1 if household had access to good road network, 0 otherwise	1.967	2.045	-0.079
Treatment variable				
Irrigation farming	1 if household participated in irrigation farming, 0 if otherwise	0.45		

Table 2
The summary statistics of household consumption, poverty and vulnerability to poverty

VariablesOutcome variables	Description	Participation (n = 180)	Non-participation (n = 220)	Mean difference
Food consumption expenditure per capita	Natural log of food consumption expenditure per capita as a welfare indicator.	3.26	3.25	0.003
Poverty gap index	The index of household poverty gap away from the poverty line	0.057	0.058	0.0007
Poverty severity index	The extent of the poverty situation of households	0.011	0.0159	0.0045
Poverty status	Poverty headcount of sampled households	0.394	0.377	0.017
Poverty vulnerability	The exposure to poverty for households who are above the poverty line	0.984	0.991	0.013

Discussions of the outcome variables

The information in Table 2 presents the summary statistics and description of the outcome variables, which are the household consumption per capita expenditure, poverty levels and poverty vulnerability.

The food consumption per capita expenditure of households that participated in irrigation farming is significantly higher than households that did not participate in irrigation farming. This implies that households that participated in irrigation farming are more likely to increase their consumption per capita expenditure. Findings from the literature [30] confirm that irrigation participants have greater potentials for more farm yields and income, which increases the level of household consumption. The poverty gap index variables show that participants in irrigation farming have a lower poverty gap index, indicating that households who practice irrigation farming have lower poverty status than the non-participants. In line with our findings, Beshir [7] has found that participation in irrigation farming reduces poverty and increase food security in Ethiopia.

The household statistics further show a lower poverty severity for the irrigation participants relative to the non-participants. This implies that non-participants constitute a bigger proportion of households experiencing severe poverty situations, perhaps due to lower farm productivities and relatively low income obtained from farm activities. This is consistent with the study of Itichia [28] who found that participants of irrigation farming have a higher tendency of reducing poverty severity.

The poverty status of the irrigation participants respondents is reasonably better than that of the non-participant which correlates with the hypothesis that irrigation farming improves rural household poverty status and food security. For poverty vulnerability, the non-participant in irrigation farming has a higher tendency of slipping into poverty in the next year if they are not already poor.

Table 3
Determinants of participation in irrigation farming (Probit model analysis)

Irrigation	Coef.	Std. Err.	*P* -value
Age	-0.002	0.007	0.825
Gender	0.848	0.223	**0.000***
Household size	-0.210	0.060	**0.000***
Flooded farm plots	-0.123	0.064	**0.054*
Income from livestock production	0.443	0.237	**0.061*
Education expenses	0.015	0.425	0.973
Remittances	0.749	0.220	**0.001***
Non-farm activity	0.065	0.182	0.722
Seasonal farming	1.062	0.207	**0.000***
Market outlet	0.377	0.078	**0.000***
Crop diversification	0.244	0.084	**0.004***
Inherited land	0.334	0.281	0.234
Leased _land	0.655	0.326	**0.044**
Access to road	-0.060	0.124	0.628
Extension service	0.720	0.218	**0.001***
Accessed credit facility	0.443	0.219	**0.043**
Farm-based association	-1.022	0.220	**0.000***
Education	0.394	0.232	**0.090*
Rented land	-0.106	0.195	0.587
Communal land	-1.087	0.341	**0.001***
Water right	0.378	0.115	**0.001***
Water access and satisfaction	0.181	0.081	**0.026**
Full time farmer	-0.355	0.219	0.104

***, ** and * represent significance level at 1%, 5% and 10%, respectively.

Determinants of participation in irrigation farming

The results in Table 3 presents the determinants of participation in irrigation farming by the farming households in the study area. The key variables that significantly explain the decision of farmers to participate in irrigation farming are discussed in this section.

The gender variable was positive and statistically significant in explaining farmers' decisions to irrigate. This implies that male farmers are more likely to participate in irrigation farming than female farmers, possibly because men have greater access to resources such as water institutions and water-related training than women. This is consistent with the findings of Mudege et al. [35] and Dlangalala and Mudhara [16], who found that women are perceived as home care providers, and thus have less access to agricultural resources than male farmers. Household size significantly reduces the probability of participation in irrigation farming. This could be attributed to the fact that larger household size is expected to be associated with a higher consumption expenditure than a smaller household size. According to Ngema et al. [41], there is a higher chance for large household sizes to be poor owing to a larger number of people required to feed. Consequently, a larger household size could redirect resources to household consumption rather than irrigation investment. The empirical findings also suggest that farmers who experience flood on their farm plots are less likely to participate in irrigation farming than farmers that did not experience flooding on their farm plots. The result agrees with the findings of Jordán and Speelman [29] who concluded that the frequent flood incidence on the farm discouraged farmers from adopting irrigation farming strategy as a climate change adaptation measure. Farmers who have excess water on their farm plot may find it unnecessary to participate in irrigation farming as enough water is available for the cultivation of crops. Although some farmers suffer from flooding caused by closeness to the riverbank, they also benefit by directly taking advantage of the excess water to irrigate their crops and improve their farm productivity. Results show that income from livestock production was statistically significant and positively influence irrigation farming participation. This is because the income generated from livestock sales could serve as capital to invest in irrigation activities. This aligns with the study of Zwedie et al. [61] who found that households with large livestock holdings are expected to have more income and increase their tendency to participate in irrigation since livestock serves as wealth and can easily be converted into cash when necessary. The importance of internal remittances (funds sent by relatives from other areas or regions within the country) to farmers is established as indicated by the results. While remittance could increase the likelihood of participation in irrigation farming, other studies reported that remittance is subject to global market volatility, making it potentially more vulnerable in the long run (Parajuli et al., [65]). Seasonal farming is statistically significant and positively influence farmers' decision to participate in irrigation farming in the study area. This could imply that farmers who only engage in farming activities on a seasonal basis may as well be involved in some other non-farm businesses which could translate into more income and more capital to invest in irrigation operations. The reduced seasonality effect on farm production could motivate farmers to consider participating in irrigation farming as this could help farmers to achieve higher yields through reduced crop failure [5].

Market outlets were positively signed and statistically influence irrigation farming participation, with markets availability key for the sales of farm produce. The result implies that farmers who have access to various marketing channels have a higher probability to sell a large proportion of their farm produce, and consequently have a higher probability of participating in irrigation farming. Thus, estimated results suggest that market access could motivate farmers to participate in irrigation farming. This is in line with the previous studies [20,43] who found a significant positive relationship between market channels and irrigation participation.

The result shows that diversification in crop production was statistically significant and positively influence the likelihood to participate in irrigation farming. Practicing crop diversification could allow farmers to engage in irrigation farming as more water resources are required to sustain the different crop types. This result supports the findings of De Sousa et al. [14] who reported that farmers who practice crop diversification often require more water to sustain the different crops, and may serve as motivation to invest in irrigation infrastructure.

In addition, access to leased land has a higher probability to participate in irrigation farming. Contrary to our findings, Fanadzo and Ncube [19] emphasized that some landowners were afraid of losing their land, causing them to pull it out of production, resulting in enormous swaths of land lying idle and reduced available land for irrigation farming practice.

Adoption of farming practices such as irrigation is sometimes limited by the availability of information and access to funding to finance the irrigation projects. Farmers may lack adequate information about the cost and access to irrigation infrastructure and its benefits. Extension services provided to farmers is statistically significant and have a positive effect in explaining farmers' participation in irrigation. This is not surprising as extension officers provide technical and managerial support on-farm practices such as irrigation. This is in line with the study of Christian et al. [9] who concluded that access to extension services increased the likelihood of adoption of irrigation technology in the Eastern Cape province of South Africa. However, farmers association negatively and statistically influenced farmers' decision to participate in irrigation farming. The negative association with the probability of participating in irrigation farming could be attributed to the active irrigators who could discourage other local farmers by making them aware of the high cost and negative impacts of the irrigation infrastructure construction on the natural watercourses and the ecological system [10]. The study of Osewe et al. [49] established a negative association with the adoption of farmer-led irrigation, confirming the results of this study. Access to credit facilities is an important variable in explaining the probability of farmers participating in irrigation farming in the study area. Credit access could allow farmers to purchase irrigation facilities and maintenance costs associated with irrigation farming. Similar to the study of Adekunle et al. [69], farmers with reliable access to credit have a higher probability of engaging in irrigation farming compared to household farmers who are faced with irrigation constraints.

Educational attainment positively and statistically influenced smallholder farmers' decision to practice irrigation farming. The result on the education variable supports the premise that better-educated farmers are more likely to engage in farming technology such as irrigation. This finding agrees with the study of Owusu-Sekyere et al. [50] who found that farmers with more knowledge would understand the benefits associated with participating in irrigation farming such as an increase in net income.

The results further indicate that farmers who cultivate on communal land are less likely to participate in irrigation farming. This highlights the fact that a lack of land ownership may impede large investments in irrigation infrastructure because communal land is allocated to a specific group of farmers for a specific type of farming purpose and inputs are mostly supplied by the government or the allocating organization. In Ethiopia, for example, communal land allotted to young farmers is strictly for tree planting, agroforestry, fodder collection for livestock, and apiculture [48]. As a result, people lack decision-making authority over the use of communal lands, and the decision to participate in irrigation is beyond the control of individual farmers.

Farmers with the water right are more likely to participate in irrigation farming. The water right creates reliable access to water resources and this significantly contributes to improving farmers' living conditions or to poverty reduction. This is supported by other studies such as Corral et al. [11] and Nonvide et al. [43] who found that water right contributes to poverty alleviation, enhance the standard of living and could motivate farmers to irrigate their farm.

Similar to a water right, the empirical results show that water access and satisfaction exhibit a significant positive impact on the likelihood of farmers to practice irrigation farming in the study area. Increased access to water could encourage rural household farmers to consider irrigation farming, as well as a sense of satisfaction for various water-related uses. Water access improves agricultural diversity, crop yield and smallholder income while also reducing vulnerability to climate variability. This is consistent with the findings of Speelman et al. [54], who found that water access is strongly related to irrigation and the income of smallholder farmers in Limpopo, South Africa.

Determinants of Irrigation participation on outcome variables

The results in Table 4 present the estimates of the outcome variables for both participants and non-participants of irrigation farming. The first part of the estimated result presents the effects of variables on the outcomes for the participants and the second part shows the estimates of the variables with the switching indicators on the outcomes for the non-participants.

The last rows of Table 4 show the correlation coefficients (ρ 0 and ρ 1) of covariance terms between the error terms of the first and second stage estimations of the ESR model. The consumption outcome has a statistical significance of 1%, indicating the possibility of self-selection bias in participation decisions. This means that unobserved factors that influence farmers' decisions to participate in irrigation also influence food consumption expenditure per capita income.

An increase in household size improves household welfare and reduces the poverty gap index, poverty severity and vulnerability to poverty for irrigation participants. However, it increases the vulnerability to poverty for the non-irrigation

Table 4
The impact of irrigation participation and non-participation on outcome variables (2nd stage ESR).

Outcome variables	Consumption (per capita expenditure) log		Poverty gap index		Poverty Severity		Poverty Vulnerability	
Participation	**Coef.**	**Std. Error**	**Coef.**	**Std. Error**	**Coef.**	**Std. Error**	**Coef.**	**Std. Error**
Age	0.0015	0.0012	-0.0004	0.0005	-0.0002	0.0002	0.0009	0.0006
Gender	**-0.1019***	0.0376	**0.0499****	0.0198	0.0078	0.005	-0.0067	0.0182
HHsize	**0.0536*****	0.0111	**-0.0187*****	0.0053	**-0.0039*****	0.0015	**-0.0178*****	0.0053
Flooded farm plot	**0.0198****	0.0104	-0.007	0.0047	-0.002	0.0014	**-0.0084***	0.0051
Income from livestock production	-0.0418	0.0521	**0.0562****	0.0233	**0.0150****	0.0063	**0.0634*****	0.0229
Education expenses	0.0519	0.0457	**-0.0750*****	0.02	**-0.0146****	0.0059	-0.0251	0.0213
Remittances	**0.1350*****	0.0468	**-0.0614*****	0.0185	**-0.0156*****	0.005	**-0.0424****	0.0184
Non-farm activity	**-0.0685***	0.0388	0.0069	0.0169	-0.0042	0.0049	0.0177	0.0178
Seasonal farming	**-0.1734*****	0.0454	**0.0764*****	0.0244	0.0094	0.0063	**0.0607*****	0.0227
Market outlet	-0.0152	0.0142	-0.0005	0.0066	-0.0009	0.0016	0.0074	0.0074
CDV	**0.0638*****	0.0133	**-0.0270*****	0.0061	**-0.0054*****	0.0016	**-0.0168*****	0.0057
Rented land	**0.0592****	0.0279	-0.0117	0.0121	-0.0057	0.0037	0.0039	0.0134
Inherited land	-0.0398	0.0451	-0.001	0.0194	-0.0053	0.0058	0.0235	0.0212
Access to road	**0.0690*****	0.0209	**-0.0387*****	0.0088	**-0.0071*****	0.0026	**-0.0464*****	0.0097
Extension services	**0.1921*****	0.0405	**-0.0941*****	0.0172	**-0.0228*****	0.0048	**-0.0822*****	0.0176
Accessed credit facility	0.0251	0.0423	-0.0137	0.0174	-0.0001	0.0052	0.0246	0.0193
Education	0.0202	0.0351	-0.0065	0.0158	0.0003	0.0046	-0.0044	0.0169
Non-participation								
Age	-0.0004	0.0014	**0.0013****	0.0006	**0.0004****	0.0002	**0.0028*****	0.0006
Gender	-0.054	0.042	0.0237	0.0174	**0.0161****	0.0068	**-0.0742*****	0.0164
HHsize	**0.0370*****	0.0136	-0.0036	0.0071	-0.001	0.0028	**0.0153*****	0.0055
Flooded farm plot	0.0166	0.0126	0.001	0.0053	0.0005	0.0019	-0.0018	0.0053
Income from livestock production	**0.1691*****	0.0418	**-0.0896*****	0.0194	**-0.0210*****	0.0067	-0.0038	0.0185
Education expenses	**0.3440*****	0.0684	**-0.1812*****	0.0286	**-0.0798*****	0.0105	-0.0264	0.0266
Remittances	-0.0746	0.0515	**0.0390***	0.0228	0.0112	0.0085	**-0.1002*****	0.0216
Non-farm activity	**0.0671***	0.04	**-0.0369****	0.015	**-0.0227*****	0.0054	-0.0121	0.0147
Seasonal farming	-0.0023	0.0415	**-0.0209**	0.0167	-0.0059	0.0066	**-0.0472*****	0.017
Market outlet	**-0.0403*****	0.013	**0.0231*****	0.0056	**0.0114*****	0.002	0.0027	0.0059
CDV	**-0.0443****	0.0224	**0.0183****	0.0086	**0.0078****	0.0032	**0.0375*****	0.0091
Rented land	0.0412	0.0372	**-0.0265***	0.0159	-0.0061	0.0056	-0.0169	0.0163
Inherited land	0.0309	0.0634	-0.0222	0.0235	-0.0043	0.0083	-0.0247	0.024
Access to road	**-0.0783****	0.0366	**0.0304****	0.0151	**-0.0122****	0.0051	-0.0159	0.0148
Extension services	0.0628	0.0473	**-0.0522*****	0.0175	**-0.0227*****	0.0063	-0.0107	0.018
Accessed credit facility	**-0.1506*****	0.0471	**0.0462****	0.0207	0.0116	0.008	-0.0087	0.021
Education	0.0753	0.053	**-0.0395***	0.0203	**-0.0140****	0.0071	**-0.0557*****	0.0211
Generalized residuals ($\rho0$)	0.408	0.407	−0.091	0.224	0.431	0.262	**-0.187*****	0.156
Interacted generalized residuals ($\rho1$)	−0.810*	0.63	0.237	0.426	−0.608	0.521	- 0.099	0.218

*Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.

participants. This could be due to the possibility of using the larger household size to their advantage by increasing the number of farm labours, thereby increasing farm productivity, and consequently, improving their welfare.

The result further indicates that household heads who are educated had a higher probability of reducing their poverty level and eliminating vulnerability to poverty. This is consistent with the study of Nigussie [42] who found that education increased productivity and subsequently lead to higher levels of welfare for the household.

The availability of adequate water on plots of land significantly and positively contributes to the consumption expenditure per capita of the participants. The reliability of the access to water for irrigation implies that farmers who participate in irrigation farming could increase the conditions of crops to increase farm productivity.

The result further indicates that investing in education training could translate into poverty reduction for householdsthatparticipates in irrigation farming. As one of the multidimensional indicators of poverty as defined by the World Bank [59], low education achievements contribute to household poverty and investment in education reduces the poverty gap index and poverty severity of the rural households.

Thus, investment in adult education programs could translate to a substantial equalizing effect owing to the impact of the returns generated by irrigation investments, and consequently led to improved household welfare.

The empirical result shows that an increase in remittances would improve household welfare while reducing the poverty gap index, poverty severity and vulnerability to poverty of the irrigation participants. The findings of this study agree with that of Musakwa and Odhiambo [37] who found that access to remittances reduces the poverty of the households.

Farmers' participation in non-farm activities showed a negative and significant relationship with the welfare outcome variable, for the participants of irrigated crop production. This could be ascribed to the transfer of resources and labour hours necessary to increase farm outputs to other non-farm activities. This result is cognizant of other studies [17] that have found a negative association of non-farm activities on household welfare. In comparison to the non-participation in irrigation farming, the result showed a significant and positive influence on household welfare while decreasing the poverty levels.

The engagement in seasonal farming by irrigation participating farmers is negatively correlated to the welfare outcome variable. The result suggests that irrigation-participating farming households who only engage in seasonal farming are less likely to improve their poverty status, including their probability of being vulnerable to poverty in the latter year. The seasonality in farming could be affected by seasonality in prices and income which may have negative consequences on the financial status of the household to improve their welfare and poverty status. Blackmore et al. [8] have reported a negative influence of seasonal farming on vulnerability to poverty and food insecurity, confirming the results of this study. For non-participation in irrigation farming, the result shows a positive and significant effect on alleviating the poverty status of rural households. This is expected because farmers who do not irrigate and only practice seasonal farming are indifferent, given the fact that they rely only on rainfall and produce during raining season, thus incur no debt or investment commitments on irrigation assets. This argument is based on the assumption that there is a negligible impact of climate change affecting the production of the participants and non-participants, otherwise, both may not be comparable. Furthermore, crop diversification for participation in irrigation farming is statistically significant and have a positive effect on household welfare. This might be because households who are a participant in irrigation farming could easily diversify and as a result, become better off in terms of reduction in poverty level as well as reducing the potential of becoming poor in the subsequent years.

These findings are consistent with those of Michler and Josephson [33], who investigated agricultural diversification on poverty dynamics. According to their results, the growing variety of crops reduces the likelihood of non-poor households becoming poor and poor households remaining poor. On the other hand, the non-participants of irrigation who practice crop diversification are more likely to experience a decrease in welfare because growing diverse crops may require irrigation support, especially given the impact of climate change. This has a negative effect on the households' poverty vulnerability.

The importance of having access to rented land on poverty reduction has been examined in Kenya by Muraoka et al. [36]. The result of this study is consistent with our findings, as there is a positive and significant effect of rented land on welfare for participants of irrigation farming. For the non-participant in irrigation farming, access to rented land showed a negative association with household poverty levels, indicating a reduction in the poverty gap index. This could be attributed to lower transaction costs only to landowners with the exclusion of irrigation operation costs [52].

Road access is statistically significant and positively influence household consumption per capita income, for rural household farmers who are under the irrigation participation group. This implies that farmers who have road access could easily access irrigation facilities, improve farm productivity and subsequently increase their household consumption. Access to motorable-road also resulted in poverty reduction, household vulnerability to poverty, for the irrigators. The result further shows that poverty severity could still increase despite having access to the road for non-irrigators. This could be ascribed to the fact that non-irrigators could have lesser yields for sale which may not contribute to improving welfare or reducing poverty levels. The findings are consistent with those of Bacha et al. [6], who found that road access improves household welfare.

Contact with extension agents has a significant effect on household welfare and poverty reduction. According to the findings, irrigators who have access to extension officers improves their welfare while significantly reducing their poverty gap index, poverty severity, and vulnerability to poverty. Extension visits were only significant in explaining poverty reductions among non-irrigators. This is consistent with expectations, as non-irrigators could also benefit from learning how to improve farm productivity, potentially narrowing the poverty severity. This is consistent with the findings of Sinyolo et al. [53] and Wossen et al. [60], who found that access to extension services increases household consumption while decreasing poverty.

Table 5
Average treatment effect of irrigation participation on outcomes.

Outcome variables	Treatment type	Participation	Non-participation	Treatment effects
Household Consumption per capita expenditure	ATT	4.33	3.87	0.45***
	ATU	3.04	3.27	0.23***
Poverty gap index	ATT	1.09	0.90	-0.20***
	ATU	0.11	0.05	-0.05***
Poverty severity	ATT	1.04	0.82	-0.22***
	ATU	0.33	0.16	-0.17***
Poverty vulnerability	ATT	1.79	1.54	-0.25***
	ATU	0.75	0.76	0.003
F-stat	0.23	0.45	0.93	

*Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level.

The falsification test results

In order to better identify the model, the study set exclusion restrictions as suggested by Di Falco and Bulte [70], which is done through the falsification tests. The falsification results (see Appendix A) show that four instruments are jointly statistically significant in the irrigation participation equation (Chi^2 2=35.95; p=0.0000) but not in the outcome equation for the participants (F=1.56; p=0.1883) and non-participants (F=0.76; p=0.5499) when household consumption per capita expenditure was used as an outcome variable. Under poverty gap, result for participants was (F=1.31; p=0.2671) and for non-participant was (F=0.34; p=0.8541), while for poverty gap index, participant was (F=1.31; p=0.2671) and non-participant was (F=0.34; p=0.8541). Under the poverty severity outcome variable, result for participant was (F=1.19; p=0.3156) and non-participant was (F=0.35; p=0.8443). Lastly for vulnerability to poverty outcome variable, results for participants (F=0.74; p=0.5670) and for non-participant (F=0.45; p=0.7386).

Treatment effects of outcome variables

The descriptive statistics of welfare and poverty outcomes presented in Table 2 shows that irrigation participants are better-off compared with the non-participants. However, these significant differences do not imply causality as the differences in the outcome variables is subject to self-selection biases. Table 5 presents the impact of participation in irrigation farming on the outcome variables using the endogenous switching estimator. The ATT and ATU were estimated after fitting the switching regression with endogenous treatment effects[1].

The result suggests that there is a significant change in terms of participation in irrigation farming. The increase in food consumption expenditure per capita shows the impact of participation in irrigation farming, which also has a statistically significant impact on reducing households' poverty gap index, poverty severity and vulnerability to poverty. The result shows that due to farmers' participation in irrigation farming, food consumption expenditure per capita increased by 45% while non-participants would have increased their consumption per capital expenditure by 23% had they participated in irrigation farming. For the poverty gap index, participating farmers lowered their poverty gap index by 20% while non-participation in irrigation-based farming could have resulted in 5% reduction in poverty gap index, had they opted to irrigate their farms. Moreover, the ATT for participation resulted in around 22% in poverty severity and this could also have led to a reduction of 17% in poverty severity for the non-participation in irrigation farming had they chosen to participate. Lastly, vulnerability to poverty was reduced by 25% owing to participation in irrigation farming while non-participants could have reduced their poverty vulnerability by 3% had they participated in irrigation farming. Overall, the results of the ATT and ATU suggests that participation in irrigation farming contribute to improving household welfare and alleviation of poverty in the study area.

Conclusion and recommendations

This study employed the ESR technique and poverty vulnerability approach to empirically analyze the factors that influence farmers' decision to participate in irrigation farming and impact on households' welfare and poverty. The gender of the household head, education, crop diversification, access to credit, water access and extension services were some of the driving factors that significantly influenced farmers' decision to participate in irrigation farming. The estimated impact analysis showed that credit access, extension contact, land ownership type, farmers' association and education training have a significant effect on increasing household consumption expenditure per capita and reduction of household poverty. This study demonstrates that irrigation participation has a favourable and significant treatment effect on household welfare, as well as significantly contribute towards the reduction in poverty gap index, poverty severity and vulnerability of household to poverty. Given the significance of irrigation participation on poverty reduction and household welfare, the government, agriculture water managers and policymakers should scale up the irrigation technology facilities, especially for the poor households, and create more awareness to improve the rural households' livelihood. In order to lift more rural households from poverty and improve livelihoods, this study recommends that government and other agricultural stakeholders should provide financial support programs such as increasing access to credit facilities to enhance farmers' willingness to participate in irrigation farming. The findings of this study suggest that improving access to credit facilities could practically encourage poor households to participate in irrigation farming and increase productivity which in turn reduces their vulnerability to poverty. More importantly, the findings of this study could be instrumental in driving the first goal of Agenda 2063 [2] and that of Sustainable Development Goal [55] in the context of achieving self-sufficiency and eliminating poverty in all forms. This could be achieved through improving food security in Africa, through increasing irrigation technology in African regions faced with drought issues which could go a long way towards lifting many Africans out of poverty, as well as eliminating poverty vulnerability of households (Agenda 2063 [67]). Moreover, policies are needed to increase access to education training which as a result could motivate non-participating farmers to consider the option of irrigating their farms. This could subsequently improve the overall agricultural productivity of the study area, hence leading to gradual poverty reduction and improved welfare for the rural households.

This study recommends that future studies should consider the use of the national poverty line to investigate whether there could be significant variations in the results when compared to studies that used the global poverty line values Eqs. (1)–(15), (16a) and (16b).

Availability of data and materials

The data that support the findings of this study can be obtained from the authors upon request.

Ethics approval and consent to participate

The study received an ethical clearance.

Consent to publish

Not applicable.

Consent to participate

Not applicable.

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Declaration of Competing Interest

The authors declare that they have no competing interests.

Appendix A. Falsification test results

Outcome variables	Participants	Non-participants
Household Consumption per capita expenditure	F (4, 154) = 1.56;Prob>F = 0.1883	F (4, 194) = 0.76;Prob>F =0.5499
Poverty gap	F (4, 154) = 1.31;Prob>F = 0.2671	F (4, 194) = 0.34;Prob>F = 0.8541
Poverty gap index	F (4, 154) = 1.31;Prob>F = 0.2671	F (4, 194) = 0.34;Prob>F = 0.8541
Poverty severity	F (4, 154) = 1.19;Prob>F = 0.3156	F (4, 194) = 0.35;Prob>F = 0.8443
Poverty vulnerability	F (4, 154) = 0.74;Prob>F = 0.5670	F (4, 194) = 0.45Prob>F = 0.7386

Appendix B. List of nomenclatures

SSA- Sub-Saharan Africa	ATU- Average treated effect on the untreated
UN- United Nations	FGT- Foster, Greer and Thorbecke
FAO- Food and Agriculture Organization	FGLS- Feasible Generalized Least Square
DAFF- Department of Agriculture, Forestry and Fisheries.	OLS- Ordinary Least Square
ESR- Endogenous Switching Regression	
IV- Instrumental variables	
ATT- Average treated effect on the treated	

CRediT authorship contribution statement

Adetoso Adebiyi Adetoro: Writing – original draft, Formal analysis. **Mjabuliseni Simon Cloapas Ngidi:** Supervision, Writing – review & editing. **Gideon Danso-Abbeam:** Writing – review & editing, Writing – original draft, Supervision. **Temitope Oluwaseun Ojo:** Writing – review & editing, Validation. **Abiodun A. Ogundeji:** Writing – original draft, Writing – review & editing.

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