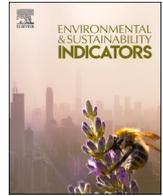# Impacts of climate change on water resources and farming community adaptation strategies in southwestern Ethiopia

Dessalegn O. Gemeda, Tadesse M. Ejeta, Gamachu B. Jabana, Zera K. Alo, Yadeta Bekele, Hailemariam M. Marta, Diribe M. Kumsa, Lidiya D. Mekonen, Getachew A. Disassa, Gadise E. Tufa, Fedhasa B. Chalchissa, Gudetu W. Bortola, Jale A. Dufera, Soreti F. Eticha, Indale N. Dejene, Tadelu Girma, Meseret Wagari, Ayantu H. Nemera, Habtamu Tamiru, Dereje H. Dehu, Hana D. Geleta, Wakjira T. Dibaba, Mehmet A. Çelik, Melahat B. Ağırkaya, Ayantu G. Leta, Zenebe R. Roba, Solomon T. Tadesse, Diriba Diba, Harison K. Kipkulei, Mitiku B. Moisa

Impacts of climate change on water resources and farming community adaptation strategies in southwestern Ethiopia

Dessalegn Obsi Gemeda [a,*] , Tadesse Mosissa Ejeta [a,w] , Gamachu Biftu Jabana [a] ,
Zera Kedir Alo [b] , Yadeta Bekele [b] , Marta Hailemariam Mamo [c] , Diribe Makonene Kumsa [d] ,
Lidiya Dereje Mekonen [d] , Getachew Abeshu Disassa [e] , Gadise Edilu Tufa [c] ,
Fedhasa Benti Chalchissa [f] , Gudetu Wakgari Bortola [g] , Jale Amanuel Dufera [f] ,
Soreti Fufa Eticha [h] , Indale Niguse Dejene [h] , Tadelu Girma [h] , Meseret Wagari [i] ,
Ayantu Habtamu Nemera [j] , Habtamu Tamiru [k] , Dereje Hinew Dehu [l] , Hana Desalegne Geleta [m] ,
Wakjira Takala Dibaba [n] , Mehmet Ali Çelik [o,v] ,
Melahat Batu Ağırkaya [p] , Ayantu Girma Leta [q] ,
Zenebe Reta Roba [r] , Solomon Tulu Tadesse [s] , Diriba Diba [t] , Harison Kiplagat Kipkulei [u,x] ,
Mitiku Badasa Moisa [h]

[a] Department of Natural Resource Management, College of Agriculture and Veterinary Medicine, Jimma University, P.O.BOX 307, Jimma, Ethiopia
[b] Department of Agricultural Economics and Agribusiness Management, College of Agriculture and Veterinary Medicine, Jimma University, P.O.BOX 307, Jimma, Ethiopia
[c] Department of Rural Development and Agricultural Extensions, College of Agriculture and Veterinary Medicine, Jimma University, P.O.BOX 307, Jimma, Ethiopia
[d] Department of Sociology, College of Social Sciences and Humanities, Jimma University, P.O.BOX 378., Jimma, Ethiopia
[e] Department of Psychology, College of Education and Behavioural Sciences, Jimma University, P.O.BOX 378, Jimma, Ethiopia
[f] Department of Environmental Sciences, College of Natural and Computational Sciences, Wollega University, P.O.BOX 395, Nekemte, Ethiopia
[g] Department of Cooperative Business Management, College of Business and Economics, Wollega University, Nekemete, P.O., 395, Nekemte, Ethiopia
[h] Department of Earth Sciences, College of Natural and Computational Sciences, Wollega University, P.O.BOX 395, Nekemte, Ethiopia
[i] Department of Natural Resource Management, Faculty of Resource Management and Economics, Wollega University, P.O.BOX 38, Shamu, Ethiopia
[j] Department of Anthropology, College of Social Sciences and Humanities, Wollega University, P.O.BOX 44, Gimbi, Ethiopia
[k] Department of Water Resources and Irrigation Engineering, Wollega University, P.O.BOX 38, Shambu, Ethiopia
[l] Department of History, College of Social Science and Humanities, Wollega University, P.O.BOX 44, Gimbi, Ethiopia
[m] Department of Accounting and Finance, College of Business and Economics, Wollega University, Nekemte, Ethiopia
[n] Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, P.O.BOX 378, Jimma, Ethiopia
[o] Department of Geography, Faculty of Arts and Sciences, Igdir University, Igdir, 76000, Türkiye
[p] Department of Finance, Banking, and Insurance, Iğdır Vocational School, Iğdır University, Türkiye
[q] Department of Hydraulic and Water Resource Engineering, College of Engineering and Technology, Wollege University, P.O.BOX 395, Nekemte, Ethiopia
[r] Department of Forestry, College of Natural Resource and Agricultural Economics, Mattu University, Bedele Campus, Bedele, Ethiopia
[s] Department of Horticulture and Plant Sciences, College of Agriculture and Veterinary Medicine, Jimma University, P.O.BOX 307, Jimma, Ethiopia
[t] Department of Animal Sciences, Faculty of Agriculture, Wollega University, P.O.BOX 395, Nekemte, Ethiopia
[u] Department of Geomatic Engineering and Geospatial Information Systems, Jomo Kenyatta University of Agricultural Technology (JKUAT), P.O.BOX 62000, Nairobi, 00200, Kenya
[v] Nakhchivan State University, Department of Geography, Nakhchivan, Azerbaijan
[w] Department of Water and Climate, Vrije Universiteit Brussel (VUB), 1050, Brussels, Belgium
[x] Climate Resilience of Human-Made Ecosystems, Center for Climate Resilience, University of Augsburg, Universitätsstraße 12, 86159, Augsburg, Germany

ARTICLE INFO

ABSTRACT

Water scarcity traps smallholder farmers in a vicious circle of poverty and challenges individual well-being. This study explores the impact of climate change on water resources and the factors influencing smallholder farmers to adopt various strategies to overcome water scarcity in the context of climate change. Multi-stage sampling techniques were used to collect data from sampled household heads (N = 1946) from five districts in the

Rainwater harvesting
Water rules

southwestern parts of Ethiopia, namely Diga, Guto Gida, Wayu Tuka, Sasiga, and Gimbi. Household-level water scarcity adaptation strategies were explored using a multivariate probit model (MVP) and multidimensional econometric model. Results show that 58.6% of household heads reported climate change impacts on water availability. Household heads exposed to agricultural yield loss tend to have greater awareness about climate change. Results show that access to water resources has a strong negative effect on the use of the rainwater harvesting strategy. Social networks, extension services and use of mass media have a positive effect on the utilization of water harvesting, water rules, protection of the watershed, public capacity building and the improvement of water infrastructures. Variables such as age, marital status, income, and limited institutional support significantly influence smallholder farmers' decisions to utilize different water scarcity adaptation strategies. This study generates practical policy implications of the impacts of water scarcity for rainfall-dependent smallholder farmers in developing countries.

1. Introduction

Water resources are essential for the daily well-being and livelihoods of people (Abanyie et al., 2023). These important resources are under pressure globally due to the combined effects of population growth, urbanization, overexploitation of water resources and climate change (Çelik et al., 2018; Guermazi et al., 2018; Allan et al., 2013; Arnell, 1999). Climate change is increasingly disrupting hydrological cycles by affecting both surface and groundwater resources (Ali et al., 2025; Granata and Nunno, 2025; Hassan et al., 2022; Olmstead, 2014). At the global level, increasing temperature trends, shifting of precipitation patterns, and increased extreme weather affect water resources (Shah and Sharifi, 2025; Dao et al., 2024).

Ecosystem services have been degraded as climate change is intensified (Ioan et al., 2025; Lungarska and Chakir, 2024; Furtak and Wolińska, 2023). The impact of climate change is diverse across various sectors with water resources among the heavily impacted sectors due to the vast reliance of the resource by various ecosystems. Climate change disproportionately affects the farming communities, which rely on rainfed agriculture and domestic use (Zahnow et al., 2025; Gilli et al., 2025; Gemeda et al., 2023; Gosling and Arnell, 2016). Rain-fed-dependent agricultural systems were highly vulnerable to climate change impacts (Lombe et al., 2024; Niang et al., 2014; Shiferaw et al., 2014). The effects of climate change on rain-fed agricultural communities are beyond the shortage of food and water; it has substantial impacts on people's migration to other regions in search of better lives and jobs.

This study plays a crucial role in contributing to our understanding of water-related resources and how climate change affects the availability and quality of water resources in Sub-Saharan Africa. It empirically examines the adaptation strategies developed by farming communities in southwestern Ethiopia to address water scarcity, providing comprehensive analyses of multiple household-level decision-making processes considering economic and social variables. This study not only generates theoretical insights but also provides practical policy implications for rainfall-dependent smallholder farmers by using a multivariate probit model (MVP). The results of this study align with the emphasis of the Intergovernmental Panel on Climate Change (IPCC), which contribute to the development of both effective climate resilience and water scarcity adaptation strategies.

Five distinct but interrelated adaptation strategies for water scarcity were analyzed using a multidimensional econometric model. While literature often focuses on a single application, this research provides a comprehensive framework encompassing both socioeconomic and institutional factors, revealing how households simultaneously adopt multiple strategies. The MVP model provides a holistic assessment by correlations among dependent variables, making the study both methodologically innovative and providing a robust analytical model that can serve as a model for other developing countries.

Due to less utilization of small-scale irrigation systems and heavy dependence on rainfed agriculture, Ethiopia is vulnerable to climate change (Conway and Schipper, 2011). Over the recent decade, drought, erratic rainfall, and flood frequency have been increasing and degrading

water availability (Malede et al., 2025; Behailu et al., 2021). The Angar and Didessa sub-basin, the upper part of the Abay basin, supports diverse rural livelihoods reliant on rain-fed agriculture, livestock, and freshwater ecosystems (Dessie and Melesse, 2012). Previous research overlooks the correlation between climate variability, ecohydrology, and socio-economic vulnerabilities at this sub-basin scale (Worqlul et al., 2018). Therefore, the present study assesses how climate change threatens water resources and factors that influence the farming communities to resolve water scarcity challenges. The results of this study aims to bolster resilience and sustainable development in rural areas.

While research on the impacts of climate change on water resources and agricultural livelihoods is increasing in Sub-Saharan Africa (Connolly-Boutin and Smit, 2015; Ofori et al., 2021), the existing literature remains limited in terms of studies that simultaneously examine multiple adaptation strategies for small-scale farmers facing water scarcity. Furthermore, many studies primarily assess water scarcity through biophysical factors (Berhanu and Bisrat, 2020; Bojago et al., 2022), with limited attention paid to the combined role of socioeconomic and institutional factors at the household level. In particular, empirical studies that holistically examine the combined effects of climate variability, social structure, and institutional support mechanisms on adaptation decisions are quite limited at the sub-basin level, especially in southwestern Ethiopia.

2. Materials and methods

2.1. Descriptions of the study area

This study was conducted in the southwestern parts of Oromia National Regional State of Ethiopia, which have the most diverse topography, climate, soil, and vegetation structures, including species composition. This study covers five districts from the western parts of Oromia National Regional State (Fig. 1). Western part of Oromia receives high precipitation from June to September.

A mixed farming agricultural system is the main economy of the study area. Several crops, such as teff, barley, wheat, millet, rice, and sesame are cultivated in this region. Because of diverse climate, this region is well known for cultivation of various vegetables (tomato, cabbage, green pepper, garlic, onion, carrot), fruits (orange, papaya, banana, avocado, mango, pineapple, and lemon) and root and tuber crops (anchote, potato, sweet potato, cassava, enset, yam, and taro). Cash crops such as coffee, tea, oilseeds, peanuts, and other spices crops are commonly grown in this region.

The study area has abundant water resources. There are different river basins in this region, including the Didessa, Anger, Dabus, and Wajja Rivers. In comparison to the northern, central, southern and eastern regions of Oromia, this area is relatively better in terms of vegetation cover and water resources. Over the recent decades, there has been intense pressure on forest resources in various places, leading to agricultural land expansions. Despite the threat posed to the natural forests by agricultural expansions and other economic activities, intact Afromontane rainforests are still found in this region (Mengist et al., 2024; Asefa et al., 2020). Afromontane forests are inherently associated

with coffee forests and are very valuable for the preservation of wild Arabica coffee and protection of tree genetic diversity (Gole et al., 2008). Both moist evergreen montane forest and Afroalpine and Sub-Afroalpine vegetation are available in this part of the country.

2.2. Research design

This study adopted a multi-stage sampling technique to select the sampled household heads from five districts in the southwestern region of Oromia. In the first stage, two zones (East Wollega and West Wollega) were selected from western part of Oromia. In the second stage, there are four districts from East Wollega Zone (Diga, Guto Gida, Wayu Tuka, and Sasiga) and one district from the West Wollega Zone (Gimbi) that were selected based on stakeholders' recommendations (Table 1). Finally, systematic random sampling methods were employed: a random starting point was selected, and then every third household was interviewed until the required sample size for each district was completed (Mehta and Naveed, 2025; Gemeda et al., 2023; Maier et al., 2023).

Due to the homogeneity of the study population, the household heads were selected at three regular intervals (Gemeda et al., 2025), which means interviewing one head of household after skipping two household heads until the required size was reached for each district. A total of 1946 sample households were selected from a total of five districts using Yamane's (1967) simplified formula (Eq. (1)).

$$n = \frac{N}{1 + N(e)^2} \qquad \text{Equation 1}$$

where n is the sample size, N is the sample of the household heads, and e is the sampling error (5%) with a 95% confidence level.

The household survey focused on socio-demographic characteristics, water resource utilization, and factors influencing the local communities to adopt different actions to minimize the impacts of water scarcity in

Table 1
Sample size of household heads.

Districts	Total household heads	Error margin	Sample size	%
Diga	12109	0.0025	387	19.9
Guto Gida	18959	0.0025	392	20.1
Gimbi	14925	0.0025	390	20
Sasiga	16113	0.0025	390	20
Wayu Tuka	12228	0.0025	387	19.9
Total	74334		1946	100

Ethiopia. A closed-ended questionnaire was designed using binary responses, yes or no, to explore water resources-related issues, including accessibility, consumption patterns, factors affecting accessibility, and existing opportunities to overcome water resources-related challenges.

Dependent variables: A total of five dependent variables: Rainwater harvesting, water rule, protecting watershed, public capacity building, and improving infrastructure were selected based on stakeholders recommendations and because they represent common, empirically studied adaptation strategies in rain-fed agricultural systems of Ethiopia and sub-Saharan Africa (Deressa et al., 2009; Gemeda et al., 2023).

Rainwater harvesting: This is a means of collecting rainwater by using different methods. It is one of the key water management measures to increase water availability in times of water scarcity. Rainwater harvesting is frequently used for both household consumption and agricultural productivity. Rainwater can be collected by using rain barrels or rainwater tank equipment and constructing catchments and channels that can be used for both domestic and non-domestic uses (García-Ávila et al., 2023; Nandi and Gonela, 2022). Rainwater is highly utilized for drinking water and other household consumption during the rainy season in rural areas of Ethiopia. It minimizes the workload of women and children in water collection from rivers. The use of
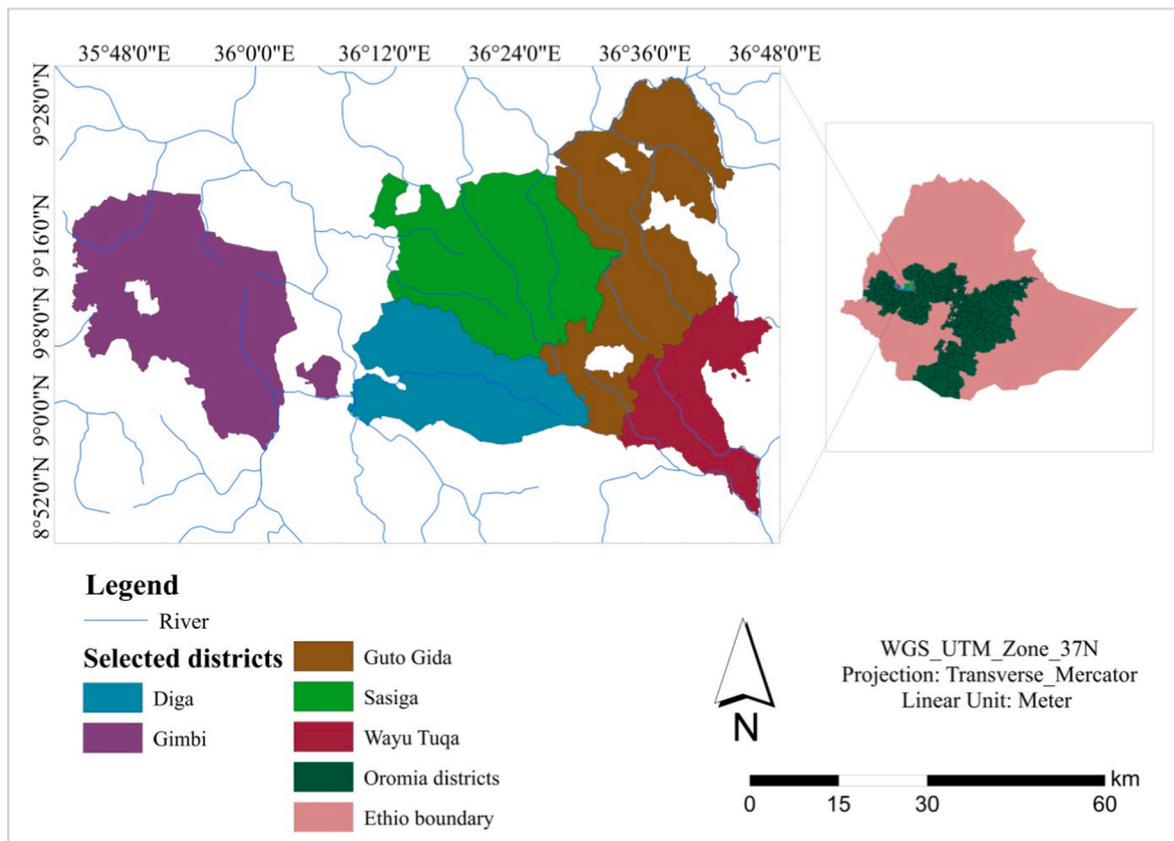

Fig. 1. Map of the study area.

Table 2
Description of dependent and explanatory variables.

Dependent variables	Mean	SD	Descriptions
Rainwater harvesting	0.38	0.48	Categorical (No = 0, Yes = 1)
Water rule	0.37	0.48	Categorical (No = 0, Yes = 1)
Protecting the watershed,	0.33	0.46	Categorical (No = 0, Yes = 1)
Public capacity building	0.36	0.48	Categorical (No = 0, Yes = 1)
Improving infrastructure	0.39	0.48	Categorical (No = 0, Yes = 1)
Explanatory variables			
Sex	0.72	0.45	Categorical (Female = 0, Male = 1)
Age of the household heads	40.99	13.09	Continuous
Marital status,	1.34	0.88	Categorical (Married = 1, Single = 2, Divorced = 3, Widowed = 4)
Family size	1.91	0.64	Categorical (1-3 = 1, 4-6 = 2, greater than 7 = 3)
Education	0.59	0.49	Categorical (Otherwise = 0, literate = 1)
Income	1.29	0.88	Categorical (Agriculture = 1, Handcraft = 2, Daily labor = 3, Employed = 4, Rent = 5, Remittance = 6, otherwise = 7)
Access to water resources	0.75	0.44	Categorical (No = 0, Yes = 1)
Social networks	0.54	0.49	Categorical (No = 0, Yes = 1)
Limited infrastructures	0.78	0.41	Categorical (No = 0, Yes = 1)
Extension services	0.43	0.49	Categorical (No = 0, Yes = 1)
Public media	0.64	0.48	Categorical (No = 0, Yes = 1)

rainwater for household consumption during the main rainy season is increasing due to less accessibility to tap water and other freshwater resources in rural areas.

Water rule: is a local context rule on water utilization and management, particularly for small-scale irrigation practices. The farming communities developed rules and restrictions for water distribution and allocation to ensure fairness and justice on the one hand and control monopolistic behaviour on the other hand in water use.

Protecting the watershed: Water quality management at the watershed scale contributes to the availability of water resources. Watershed management is one key measure that can minimize the problem of water scarcity in rainfed-dependent agricultural communities (Vema et al., 2018). Poor water quality is the result of watershed degradation (Gavrilaş et al., 2025; Zhang and Barten, 2009). Protecting and governing watersheds requires strong collaboration between local communities and policymakers (Lalika et al., 2015).

Public capacity building: Public capacity building refers to the development of public knowledge and skills on water resources and

springs, drilling wells, and constructing and maintaining small dams.

Explanatory variables: explanatory variables are used to predict the most important factors that influence the farming communities to utilize different adaptation strategies towards water scarcity. In this study, eleven explanatory variables, namely, sex, age, marital status, family size, education, income, access to water resources, social networks, limited infrastructures, extension services, and access to media resources, were included in the model as shown in Table 2.

2.3. Data analysis

Data was analyzed using frequency counts that were calculated for each item, summarizing the total number of Yes (1) and No (0) responses. To predict water scarcity adaptation options by smallholder farmers, factors such as demographic variables, economic factors, community perception of climate change, effects of climate change on water availability, role of social networks, the effects of limited infrastructural development, role of agricultural extension services, and public mass media were considered.

Data were collected through the socioeconomic survey (N = 1946) was analyzed using the Stata software Version 15. The multivariate probit (MVP) model was employed to explore factors that influence smallholder farmers' decisions to adopt various strategies to minimize the impacts of water scarcity on agricultural production and other socioeconomic activities. The MVP model has been utilized by different studies to explore factors influencing the local communities to choose various adaptation options (Yu et al., 2025; Gemeda et al., 2023; Ojo et al., 2021).

The MVP measures multiple and correlated binary outcomes simultaneously (Delporte et al., 2025; Ntsoane et al., 2025; Shah and Sharifi, 2025). Empirically, the choice of adaptation strategies using the MVP model can be modelled as follows. Let Y^*i_k represent the benefits to the household that adopts different strategies like rainwater harvesting (Y_1), water rule (Y_2), protecting watershed (Y_3), public capacity building (Y_4) and improving infrastructure (Y_5). The household decides to adopt the kth adaptation strategies if the benefits are deemed to be higher. The net benefit ($Y^* i_k$) that the household gets from choosing adaptation strategies is a latent variable determined by observed explanatory variables (X_i) and the error term εi).

$$Y^*i_k = X^i \beta k + \beta_i \text{ (k = Y1, Y2, Y3, Y4, Y5)} \qquad \text{(Equation 2)}$$

The unobserved preference in equation (2) translates into the observed binary outcome equation for each adoption as follows:

$$Y_{ik} = \begin{cases} 1 \text{ if } X^i + \beta_i > 0 \\ 0 \text{ otherwise} \end{cases} \text{ (k = Y1, Y2, Y3, Y4, Y5)} \qquad \text{(Equation 3)}$$

where Y_i represents a vector of dependent variables (adaptation choice to water scarcity)

factors that influence water scarcity adaptation options.

Improving infrastructure: Improving infrastructure in this study refers to upgrading and maintenance of water infrastructure, water source rehabilitation, building small-scale dams and reservoirs, water treatment plants and other activities that can improve the availability of water resources. Water infrastructure includes protecting wells and

X^i is a matrix of explanatory variable, β_k is a vector of coefficients,

εi is a random error term, n is number of observation with zero means and unitary variance

The MVP is an econometric technique used to simultaneously predict multiple binary (0/1) outcome variables, accurately reflecting real-world decision-making processes by accounting for potential correlations among these outcomes (Cappellari and Jenkins, 2003; Chib and Greenberg, 1998). In situations where decisions are interdependent, it increases predictive power by modelling the relationships between dependent variables (Manda et al., 2023).

The MVP is widely used in multiple strategy or policy research, such as agriculture (Li & Zhang, 2023; Kassie et al., 2022; Hassen et al., 2021), health and sociology (Wang and Zhang, 2024), and environmental (Nguyen and Tran, 2023) research, where multiple strategy or policy choices are involved (Manda et al., 2023). The model goes beyond classical single-variable probit analysis by revealing the joint effect of both observed and unobserved factors on multiple outcomes. As simulation-based estimation methods are used, the model generates robust statistical results while also providing more realistic data interpretations for policymakers and researchers.

3. Results and discussions

3.1. Socio-demographic characteristics

The total sampled population was 9056, with an average family size of 4.65. Among the total 9056 population, children under 15 years are 2754 (30.41%), while adults aged 15 to 64 comprise 5966 (65.88%), and the older people, aged 65 and above, are 336 (3.71%). More than 85% of the household heads are married. The high proportion of married households suggests that extended family structures are dominant and that may influence collective decision-making processes in water use and adaptation strategies.

The economically active population, which includes both children and older people, accounts for about 34.12%. The male-headed households account for about 72%, while those headed by females make up 28%. The fact that the vast majority of households are headed by men indicates that a gender-based structure is still prominent in decision-making processes. This reveals that men play a decisive role in accessing water resources and adopting adaptation strategies, consistent with previous studies in Ethiopia and other parts of Sub-Saharan Africa (Van

and Holvoet, 2016; Eaton et al., 2021; Assefa and Gebrehiwot, 2023; Fonjong and Zama, 2023).

Concerning household size, about 58% of a family have four to six children, while 16.5% have more than seven family members. A large family size is more exposed to water stress than small family size. According to Seaman et al. (2014), large households typically have higher water demands, which put more strain on already scarce water supplies. More than half of the household heads are literate. Majority of the literate household heads completed primary school. Specifically, 767 household head completed primary school, 366 completed high school, and only 6 household heads attained tertiary education. Level of education can influence people's attitudes towards climate change (Köse et al., 2025; Hoekstra et al., 2024). The predominance of primary education and the small percentage of higher education achievers suggest limited access to advanced information and technical knowledge, despite the seemingly high literacy rates. Higher levels of education improve farmers' capacity to identify climate risks and implement practical adaptation measures, according to earlier research (Hassan and Knigh, 2023). In this situation, households' ability to adapt and their use of information-intensive adaptation options may be limited by low education levels. Like other parts of Ethiopia, most of the household heads are dependent on agriculture (87.3%), which is vulnerable to climate change (Table 3).

3.2. Impact of climate change on water resource

Results show that the farming communities perceived the effects of climate change on water resources. About 1141 household heads (58.6%) understand climate change impacts on water resources over the past decades. Those household heads who had already been exposed to yield loss tend to have more knowledge of the effects of climate change on their economy and well-being. The farming communities can easily understand climate change and its associated impacts based on their experiences (Chowdhury et al., 2025; Ricart et al., 2025; Sheikh et al., 2024). The household heads have noted the occurrences of climate extremes such as excess rainfall, shortage of rainfall, drought occurrence and warmer temperatures (Table 4).

The strong dependence on subsistence rainfed agriculture further amplifies exposure to climate variability and extreme events. High agricultural dependence, combined with limited income diversification, reduces households' resilience to economic and climatic shocks, a pattern widely observed in rural Ethiopia (Zeleke et al., 2021; Tofu et al., 2022; Maru et al., 2021). Limited reliance on remittances and non-farm income sources suggests that migration plays only a marginal role in buffering climate risks, thereby reinforcing structural vulnerability. Overall, these socio-economic conditions collectively increase susceptibility to water scarcity and climate-related stress, corroborating findings reported by Bizelk and Tadesse (2023).

Climate change is evident in many regions, and various entities such as government agencies, non-governmental organizations, educational institutions, agricultural extension services, and different media outlets, including newspapers, radio, and television, along with capacity building and training initiatives, serve as a main source of information (Table 5). Local mass media (63.6%), agricultural extension services (42.5%), and government agencies (33%) are the top three channels to disseminate climate change and water resources-related information.

Table 3
Socio-demographic characteristics of respondents (N = 1946).

Respondent characteristics			
All measures		Frequency	Percentage
Sex	Male	1402	72
	Female	544	28
	Total	1946	100
Marital status	Married	1667	85.7
	Single	69	3.5
	Divorced	44	2.3
	Widowed	166	8.5
	Total	1946	100
Household family size	1-3	498	25.6
	4-6	1127	57.9
	>7	321	16.5
Religion	Protestant	1186	60.9
	Orthodox	488	25.1
	Muslim	161	8.3
	Catholic	98	5
	Wakefata	13	0.7
	Total	1946	100
Education status of the household members	Literate	1139	58.5
	Otherwise	807	41.5
Main source of household income	Agriculture	1699	87.3
	Daily laborer	142	7.3
	Handcrafts	63	3.2
	Remittance	22	1.1
	Others	9	0.5
	Total	1946	100

Table 4
Key indicators of climate change (N = 1946).

Indicators	Frequency	Percent
Heavy rainfall	367	18.85
Rainfall shortage	327	16.80
Drought occurrence	245	12.58
High temperature	202	10.38
Total	1141	58.6

Table 5
Household sources of information about climate change and water resources.

Where do you typically obtain information about climate change and water resources?	Household Response	Frequency	Percentage
Government agencies responsible for environmental protection	Yes	642	33
	No	1304	67
NGOs working on climate change and environmental advocacy	Yes	570	29.3
	No	1376	70.7
Educational institutions	Yes	599	30.8
	No	1347	70.7
Extension services	Yes	828	42.5
	No	1118	57.5
Local media outlets: newspapers, radio stations, and television	Yes	1238	63.6
	No	708	36.4
Training programs and capacity-building initiatives	Yes	742	38.1
	No	1204	61.9

About 1029 (52.9%) of the household heads reported that climate change is affecting water availability, which can influence agricultural production and community livelihoods and well-being. About 976 (50.2%) of the respondents reported that there is a substantial decline in rivers and streams during dry seasons. Declining surface-water availability, including reduced streamflow during dry periods, is widely recognized as a key climate-related threat in drought-prone farming systems (Nimma et al., 2025; Chan et al., 2021; Arsiso et al., 2017; Alauddin and Sarker, 2014). Almost half of the household heads, 970, comprising 49.8%, reported lower water levels. Low water levels contribute to water scarcity, particularly for irrigation during dry seasons. Increasing frequency of water shortage (42.3%) and changes in rainy seasons (39.4%) were other key threats. Water availability and food security are directly interrelated (Liu et al., 2025; Ringler et al., 2022; Vallino et al., 2020).

3.3. Adaptation strategies to minimize water scarcity

The radar chart below visually summarises the regression coefficients of explanatory variables affecting five adaptation options to water scarcity (Fig. 2). The variables (extension services), social

networks, and media (media) have high effects across all strategies; this indicates that social awareness and information dissemination significantly encourage water adaptation behaviours (Oumer et al., 2025). Overall, the graph visually reflects a complex decision-making process in which both individual and structural factors influence the adoption of water adaptation strategies.

The variable sex significantly influences the use of different capacity building activities [Coefficient = −0.134 and p = 0.069]. The variable age significantly influences the use of water rules [Coefficient = −0.005 and p = 0.058], watershed protection [Coefficient = 0.008 and p = 0.003] and infrastructural improvement [Coefficient = −0.007 and p = 0.008]. Among the demographic variables, marital status showed a statistically positive influence at 1% significance level on the use of water rule, protecting the watershed, public capacity building, and improving infrastructures (Table 6). Among all explanatory variables, family size does not influence the adoption of different adaptation choices to reduce the potential impacts of water scarcity.

The importance of social capital, institutional support, and information access is emphasized in the discussion of adaptation strategies. Due to their wide reach and affordability, mass media emerge as a crucial tool for increasing awareness, and perceptions of climate risk are further shaped by individual experiences and a variety of information sources (Zhang et al., 2025; Perga et al., 2023; Rosenthal, 2022). Consistent with previous research highlighting the role of social capital in climate adaptation, the positive impact of social networks across the majority of adaptation strategies highlights the significance of community cohesion and collective action in managing water scarcity (Navarro et al., 2017; Carmen et al., 2022; Li and West, 2024). Understanding adaptive capacity of the smallholder farmers to water scarcity challenge is essential for sustainable water management and agricultural productivity (Nega et al., 2025; Touch et al., 2024).

Conversely, the negative effect of water access on rainwater harvesting adoption suggests a substitution effect, whereby households with relatively secure water access are less inclined to invest in alternative water management practices. Institutional constraints and education show strategy-specific effects, indicating that a complex interaction between household characteristics and enabling environments shapes adaptation decisions. Gender- and age-related differences
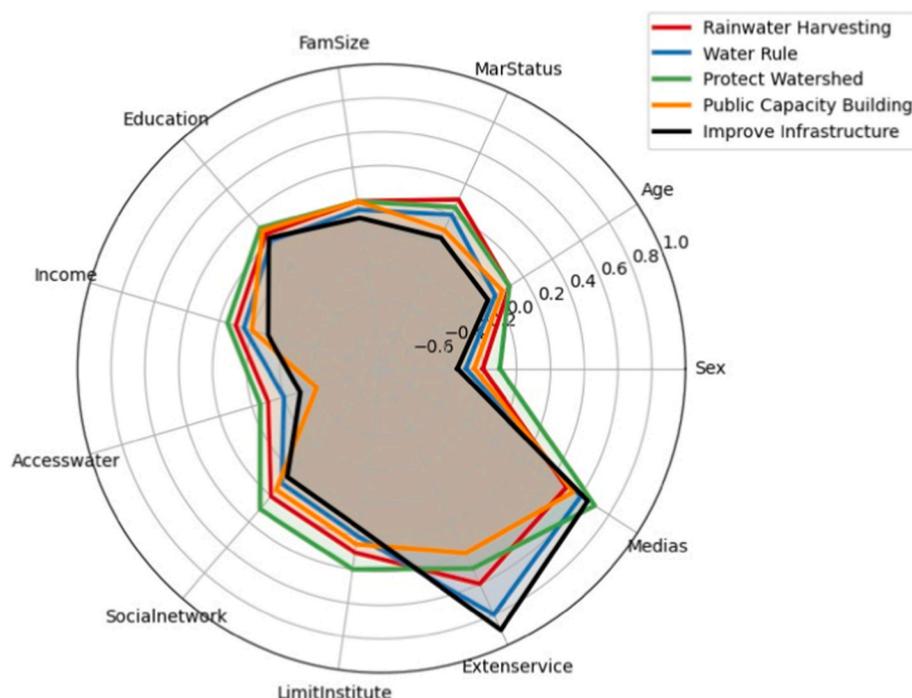

Fig. 2. Radar chart of coefficients across five strategies.

Table 6
Multivariate probit model output and determinants of water scarcity adaptation strategies.

Explanatory variables	Water scarcity adaptation strategies									
	Rainwater Harvesting		Water rule		Protect watershed		Public capacity building		Improve Infrastructure	
	Coef. (Std.Err)	p-value	Coef. (Std.Err)	p-value	Coef. (Std.Err)	p-value	Coef. (Std.Err)	p-value	Coef. (Std.Err)	p-value
Sex	−0.106 [0.067]	0.115^{ns}	0.034 [0.070]	0.630^{ns}	0.006 [0.071]	0.932^{ns}	−0.134 [0.069]	0.054**	−0.212 [0.067]	0.002*
Age	−0.001 [0.003]	0.655^{ns}	−0.005 [0.003]	0.058^{***}	0.008 [0.003]	0.003*	−0.003 [0.003]	0.323^{ns}	−0.007 [0.003]	0.008*
MarStatus	−0.050 [0.037]	0.173^{ns}	0.102 [0.037]	0.006*	0.105 [0.037]	0.004*	0.136 [0.036]	0.000*	0.106 [0.035]	0.003*
FamSize	0.078 [0.048]	0.107^{ns}	0.056 [0.051]	0.268^{ns}	−0.029 [0.051]	0.569^{ns}	0.045 [0.050]	0.367^{ns}	0.063 [0.049]	0.196^{ns}
Education	0.089 [0.069]	0.192^{ns}	−0.031 [0.071]	0.661^{ns}	0.125 [0.072]	0.081*	0.075 [0.070]	0.284^{ns}	0.093 [0.068]	0.173^{ns}
Income	0.009 [0.021]	0.668^{ns}	0.011 [0.022]	0.623^{ns}	−0.063 [0.023]	0.006*	−0.060 [0.022]	0.006*	−0.046 [0.021]	0.027*
Accesswater	−0.581[0.070]	0.000*	−0.122 [0.077]	0.115^{ns}	−0.105 [0.079]	0.184^{ns}	0.007 [0.079]	0.928^{ns}	0.055 [0.077]	0.473^{ns}
Socialnetwork	0.231 [0.067]	0.001*	0.356 [0.070]	0.000*	0.391 [0.068]	0.000*	0.300 [0.067]	0.000*	0.151 [0.066]	0.021*
LimitInstitute	0.256 [0.083]	0.002*	−0.030 [0.083]	0.719^{ns}	0.436 [0.090]	0.000*	0.278 [0.082]	0.001*	0.240 [0.079]	0.002*
Extenservice	−0.489 [0.067]	0.000*	0.968 [0.065]	0.000*	0.304 [0.066]	0.000*	0.623 [0.064]	0.000*	0.764 [0.062]	0.000*
Medias	0.327 [0.067]	0.000*	0.361 [0.069]	0.000*	0.560 [0.072]	0.000*	0.488 [0.068]	0.000*	0.480 [0.066]	0.000*
_cons	−0.283 [0.172]	0.100	−1.167 [0.184]	0.000	−1.854 [0.191]	0.000	−1.373 [0.185]	0.000	−1.056 [0.178]	0.000

Values outside the brackets were the Coefficient, and values inside the brackets were the Standard Error.

1%, 5%, and 10% significance level is indicated by *, **, ***, respectively.

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2 (10) = 1018.73.

Prob > chi2 = 0.0000.

Multivariate probit (SML, draws = 5)   Number of orbs = 1946.

Log likelihood = −5040.4357   Wald ch2 (55) = 1021.29.

  Prob > chi2 = 0.

further suggest that adaptation preferences vary across demographic groups, supporting earlier evidence that adaptation behavior is not uniform within rural communities (Belay et al., 2022; Deressa et al., 2009). Finally, the negative influence of income on infrastructure-intensive strategies highlights financial barriers faced by low-income households, limiting their ability to invest in long-term and capital-intensive adaptation measures (Saha et al., 2019).

The adoption of water scarcity adaptation strategies is heavily influenced by social networks, extension services, and the media, underscoring the significance of community-based interventions. The creation and development of regional water user organizations, watershed committees, and farmer cooperatives that promote group decision-making and information exchange should be given top priority by policymakers. These community-driven strategies can strengthen social cohesiveness and encourage the spread of low-cost adaptation techniques like rainwater collection and locally enforced water-use regulations. Institutional support and information access suggest that water scarcity adaptation strategies should be better integrated into national climate and water policies, including Ethiopia's Climate-Resilient Green Economy (CRGE) strategy and national adaptation planning frameworks. Institutional and policy approaches aimed at minimizing water loss and enhancing the efficiency of water development initiatives are essential (Tefera et al., 2023). Aligning household-level adaptation initiatives with existing national policies can improve coordination among government agencies, extension services, and non-governmental organizations, ensuring that local adaptation efforts are supported by broader institutional mechanisms.

Water security is increasingly recognized as a multidimensional concept that involves complex economic, social, and environmental trade-offs, thereby requiring adaptive and integrative management approaches under conditions of climate change (Pahl-Wostl et al., 2013). Evidence from rural smallholder settings also shows that farmers' perceptions of climate risk and their adaptation responses are strongly shaped by socio-economic and institutional conditions, underscoring the need for policy and programming that prioritize awareness, capacity building, and locally appropriate support mechanisms (Gandure et al., 2013). Similarly, research from Odisha (India) highlights that rising temperatures, erratic rainfall, and extreme events can undermine agricultural productivity and food security and translate into direct livelihood pressures for rural households, reinforcing the need for targeted, climate-resilient interventions (Rout and Sharma, 2024).

Consistent with basin-scale evidence from northern India, where

precipitation projections remain highly uncertain and natural variability can dominate the climate-change signal, resilience-focused adaptation and coherent planning at catchment/river-basin scales are recommended to reduce vulnerability under both anticipated and unanticipated conditions (Moors et al., 2011). Prioritizing investments in capacity-building initiatives, agricultural extension services, and affordable water infrastructure, such as protected wells, rainwater harvesting systems, and small-scale reservoirs, can reduce adoption barriers for low-income households. By focusing on scalable, cost-effective, and community-oriented solutions, policymakers can strengthen smallholder farmers' adaptive capacity while advancing long-term sustainability goals for water security, climate resilience, and rural livelihoods in Ethiopia.

4. Conclusions

This study explores factors influencing smallholder farmers to adopt various adaptation strategies to overcome water scarcity in the presence of climate change. Results show that rainwater harvesting, water rule, protecting the watershed, public capacity building, and improving infrastructure are key adaptation to water scarcity. This study provides a comprehensive framework encompassing both socioeconomic and institutional factors, demonstrating how households simultaneously adopt multiple strategies. A decline in water resources due to over-exploitation under rapid population growth expected to be severe challenge for rural communities, which typically possess limited adaptive capacity and resource constraints.

More than half of the respondents perceived the effects of climate change on water resources. Household heads exposed to climate change impacts tend to be more willing to adopt various strategies, while those who are less exposed were reluctant to adopt adaptation measures. The local communities can easily understand climate change and its associated impacts based on their experiences. Access to water resources shows a strong negative effect on the adoption of the rainwater harvesting strategy. The social networks variable has a positive effect in almost all strategies, which indicates that social bonding and solidarity within the community play a major role in managing water scarcity. This study will support decision makers in investing in adaptation strategies for water scarcity by enhancing public capacity building and upgrading water infrastructure development.

This study demonstrates that effective adaptation to water scarcity among smallholder farmers emerges from the interaction of climatic

exposure, social capital, and institutional support rather than from water availability alone. The findings highlight that investments in extension services, public capacity building, information dissemination, water recycling, and fostering cross-sectoral cooperation are essential to minimize the impacts of water scarcity. Moreover, an integrated and people-centered decision-making framework that provides affordable water infrastructure can reduce vulnerability among resource-constrained rural households, enhance collective resilience to climate extremes, and support the development of sustainable and scalable water governance strategies in the face of ongoing climate change and population pressures.

CRediT authorship contribution statement

Dessalegn Obsi Gemeda: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Tadesse Mosissa Ejeta:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Gamachu Biftu Jabana:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Zera Kedir Alo:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Yadeta Bekele:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marta Hailemariam Mamo:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Diribe Makonene Kumsa:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Lidiya Dereje Mekonen:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Getachew Abeshu Disassa:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Gadise Edilu Tufa:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Fedhasa Benti Chalchissa:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Gudetu Wakgari Bortola:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Jale Amanuel Dufera:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Soreti Fufa Eticha:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Indale Niguse Dejene:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Tadelu Girma:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Meseret Wagari:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Ayantu Habtamu Nemera:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Habtamu Tamiru:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Dereje Hinew Dehu:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Hana Desalegne Geleta:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Wakjira Takala Dibaba:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Mehmet Ali Çelik:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Melahat Batu Ağırkaya:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Ayantu Girma Leta:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Zenebe Reta Roba:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Solomon Tulu Tadesse:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Diriba Diba:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Harison Kiplagat Kipkulei:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis. **Mitiku Badasa Moisa:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Funding

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Data availability

Data will be made available on request.

References

Abanyie, S.K., Ampadu, B., Frimpong, N.A., Amuah, E.E.Y., 2023. Impact of improved water supply on livelihood and health: Emphasis on Doba and Nayagnia, Ghana. Innov. Green Dev. 2 (1), 100033.

Ali, M.H., Biswas, P., Hassan, S.M.Q., Islam, M.A., 2025. Climate change and its impacts on hydrological regimes over the Bengal delta. Results Eng. 25. Article 103861.

Allan, C., Xia, J., Pahl-Wostl, C., 2013. Climate change and water security: challenges for adaptive water management. Curr. Opin. Environ. Sustain. 5 (6), 625–632.

Alauddin, M., Sarker, M.A.R., 2014. Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation. Ecol. Econ. 106, 204–213.

Arnell, N., 1999. Climate change and global water resources. Glob. Environ. Change 9, S31–S49.

Arsiso, B.K., Tsidu, G.M., Stoffberg, G.H., Tadesse, T., 2017. Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia. Clim. Risk Manag. 18, 21–33.

Asefa, M., Cao, M., He, Y., Mekonnen, E., Song, X., Yang, J., 2020. Ethiopian vegetation types, climate and topography. Plant Divers. 42 (4), 302–311.

Assefa, E., Gebrehiwot, G., 2023. Gender dimensions of climate change adaptation in Tigray, Ethiopia Author links open overlay panel. Glob. Environ. Change 82, 102737.

Behailu, G., Ayal, D.Y., Zeleke, T.T., Ture, K., Bantider, A., 2021. Comparative analysis of meteorological records of climate variability and farmers' perceptions in Sekota Woreda, Ethiopia. Clim. Serv. 23, 100239.

Belay, A., Recha, J., Woldeamanuel, T., Morton, J., 2022. Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. Heliyon 8 (7), 2-13.

Berhanu, B., Bisrat, E., 2020. Alleviating water scarcity in the central rift valley Lakes through an inter-basin water transfer, Ethiopia. Nat. Resour. 11 (12), 554–568.

Bizelk, B., Tadesse, M., 2023. Socio-economic and institutional determinants of farmers' adaptation strategies to climate change and variability in Sidama Region, Ethiopia. J. Forestry Nat. Res. 2 (2), 29–41.

Bojago, E., Senapathy, M., Ngare, I., Dado, T.B., 2022. Assessment of the effectiveness of biophysical soil and water conservation structures: a case study of Offa Woreda, Wolaita Zone, Ethiopia. Appl. Environ. Soil Sci. 2022, 1–11.

Carmen, E., Fazey, I., Ross, H., Bedinger, M., Smith, F.M., Prager, K., McCiymont, K., Morrisson, D., 2022. Building community resilience in a context of climate change: the role of social capital. Ambio 51, 1371–1387.

Chan, S.S., Seidenfaden, I.K., Jensen, K.H., Sonnenborg, T.O., 2021. Climate change impacts and uncertainty on spatiotemporal variations of drought indices for an irrigated catchment. J. Hydrol. 601, 126814.

Chib, S., Greenberg, E., 1998. Analysis of multivariate probit models. Biometrika 85 (3), 347–361.

Cappellari, L., Jenkins, S., 2003. Multivariate probit regression using simulated maximum likelihood. STATA J. 3 (3), 278–294.

Connolly-Boutin, L., Smit, B., 2015. Climate change, food security, and livelihoods in Sub-Saharan Africa. Reg. Environ. Change 16 (2), 385–399.

Chowdhury, J.M.A.S., Khalek, Md A., Kamruzzaman, Md, 2025. Farmers' climate change perception, impacts and adaptation strategies in response to drought in the Northwest area of Bangladesh. Clim. Serv. 38, 100540.

Conway, D., Schipper, E.L.F., 2011. Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Glob. Environ. Change 21 (1), 227–237.

Çelik, M.A., Bayram, H., Özüpekçe, S., 2018. An assessment on climatological, meteorological and hydrological disasters that occurred in Turkey in the last 30 years (1987-2017). Int. J. Geogr. Geogr. Educat. (38), 295–310.

Dao, P.U., Heuzard, A.G., Le, T.X.H., Zhao, J., Yin, R., Shang, C., Fan, C., 2024. The impacts of climate change on groundwater quality: a review. Sci. Total Environ. 912, 169241.

Dessie, T., Melesse, A.M., 2012. Water resources and soil erosion problems in the Didessa sub-basin of the Blue Nile basin, Ethiopia. Water Resour. Manag. 26 (9), 2419–2435.

Delporte, M., Verbeke, G., Fieuws, S., Molenberghs, G., 2025. Accelerating computation: A pairwise fitting technique for multivariate probit models. Comput. Stat. & Data Anal. 203, 108082.

Deressa, T., Hassan, R., Ringler, C., Alemu, T., Yesuf, M., 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Change 19 (2), 248–255.

Eaton, J., Krishna, A., Sudi, C., George, J., Magomba, C., Eckman, A., Houck, F., Taukobong, H., 2021. Gendered social norms change in water governance structures through community facilitation: evaluation of the UPWARD intervention in Tanzania. Front. Sociol. 6, 672989.

Furtak, K., Wolińska, A., 2023. The impact of extreme weather events as a consequence of climate change on the soil moisture and on the quality of the soil environment and agriculture – a review. Catena 231, 107378.

Fonjong, L., Zama, R., 2023. Climate change, water availability, and the burden of rural women's triple role in Muyuka, Cameroon. Glob. Environ. Change 82, 2–12.

Gandure, S., Walker, S., Botha, J.J., 2013. Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. Environ. Dev. 5, 39–53.

García-Ávila, F., Guanoquiza-Suárez, M., Guzmán-Galarza, J., Cabello-Torres, R., Valdiviezo-Gonzales, L., 2023. Rainwater harvesting and storage systems for domestic supply: an overview of research for water scarcity management in rural areas. Results Eng. 18, 101153.

Gavrilaș, S., Burescu, F.-L., Chereji, B.-D., Munteanu, F.-D., 2025. The impact of anthropogenic activities on the catchment's water quality parameters. Water 17, 1791.

Gemeda, D.O., Korecha, D., Garedew, W., 2023. Determinants of climate change adaptation strategies and existing barriers in Southwestern parts of Ethiopia. Clim. Serv. 30, 100376.

Gemeda, D.O., Katebu, Y.G., Moisa, M.B., Roba, Z.R., Wolteji, B.N., 2025. Implications of forest loss and degradation on human-grivet monkey co-existence: challenges and current mitigation strategies in Southwestern Ethiopia. Environ. Monit. Assess. 197, 959.

Gilli, M., Calcaterra, M., Emmerling, J., Granella, F., 2025. Climate change impacts on the within-country income distributions. J. Environ. Econ. Manag. 127, 103012.

Gole, T.W., Borsch, T., Denich, M., Teketay, D., 2008. Floristic composition and environmental factors characterizing coffee forests in southwest Ethiopia. For. Ecol. Manag. 255 (7), 2138–2150.

Gosling, S.N., Arnell, N.W., 2016. A global assessment of the impact of climate change on water scarcity. Clim. Change 134 (3), 371–385.

Granata, F., Nunno, F.D., 2025. Rising threats to groundwater recharge: adaptive strategies for the Sahel under climate change. Groundw. Sustain. Dev. 30, 101468.

Guermazi, E., Milano, M., Reynard, E., Zairi, M., 2018. Impact of climate change and anthropogenic pressure on the groundwater resources in arid environment. Mitig. Adapt. Strategies Glob. Change 24 (1), 73–92.

Hassan, W.H., Hussein, H.H., Nile, B.K., 2022. The effect of climate change on groundwater recharge in unconfined aquifers in the western desert of Iraq. Groundw. Sustain. Dev. 16, 100700.

Hassen, S., Bachewe, F., Abate, G., 2021. Adoption of multiple agricultural technologies: do complementary and substitute relationships matter? Agric. Econ. 56 (6), 1001–1017.

Hassan, B., Knigh, J., 2023. Adaptation to climate change and variability by farming households in north-central Nigeria. Sustainability 15 (16309), 2–16.

Hoekstra, A.G., Noordzij, K., de Koster, W., van der Waal, J., 2024. The educational divide in climate change attitudes: understanding the role of scientific knowledge and subjective social status. Glob. Environ. Change 86. Article 102851.

Ioan, S., Roseo, F., Brambilla, M., 2025. Mountain ecosystem services under a changing climate: a global perspective. Ecosyst. Serv. 73. Article 101732.

Köse, N., Ersöz, E., Demir, A.S., 2025. Social perception analysis towards climate change and green transformation: Karabük case study. Extr. Ind. Soc. 24, 101755.

Kassie, M., Fisher, M., Shiferaw, B., 2022. Sustainable agricultural practices and farmer welfare: evidence from multiple adoption decisions in Sub-Saharan Africa. World Dev. 152, 105–118.

Lalika, M.C.S., Meire, P., Ngaga, Y.M., 2015. Exploring watershed conservation and water governance along Pangani River Basin, Tanzania. Land Use Policy 48, 351–361.

Liu, H., Gao, X., Li, C., Cai, Y., Song, X., Zhao, X., 2025. Intercropping increases plant water availability and water use efficiency: a synthesis. Agric. Ecosyst. Environ. 379, 109360.

Li, Y., Zhang, X., 2023. Climate-smart agriculture adoption under uncertainty: a multivariate probit approach in rural China. J. Environ. Manag. 325, 116–128.

Li, Y., West, J., 2024. The role of social capital in the impact of multiple shocks on households' coping strategies in underdeveloped rural areas. Sci. Rep. 14, 13789.

Lombe, P., Carvalho, E., Rosa-Santos, P., 2024. Drought dynamics in Sub-Saharan Africa: impacts and adaptation strategies. Sustainability 16, 9902.

Lungarska, A., Chakir, R., 2024. Projections of climate change impacts on ecosystem services and the role of land use adaptation in France. Environ. Sustain. Indic. 22, 100369.

Maier, C., Thatcher, J.B., Grover, V., Dwivedi, Y.K., 2023. Cross-sectional research: a critical perspective, use cases, and recommendations for IS research. Int. J. Inf. Manag. 70, 102625.

Malede, D.A., Elumalai, V., Andualem, T.G., Mekonnen, Y.G., Yibeltal, M., Demeke, G.G., Alamirew, T., Kassaye, S.M., Hagos, Y.G., Kassie, A.E., Kassa, M., Berihun, G.S., Ray, R.L., 2025. Understanding flood and drought extremes under a changing climate in the Blue Nile Basin: a review. Environ. Sustain. Indic. 26, 100638.

Manda, J., Alene, A., Mukuma, C., 2023. Adoption of multiple climate-smart agricultural practices in Zambia: a multivariate probit analysis. Clim. Dev. 15 (3), 210–223.

Maru, H., Haileslassie, A., Zeleke, T., Esayas, B., 2021. Analysis of smallholders' livelihood vulnerability to drought across agroecology and farm typology in the upper awash Sub-Basin, Ethiopia. Sustainability 13 (9764), 2–28.

Mehta, R., Naveed, M., 2025. Chapter 37 - cross-sectional studies: design, measures, classic example. In: Eltorai, Adam E.M., Liu, Tao, Mehta, Devendra I., Horvath, Karoly (Eds.), Handbook for Designing and Conducting Clinical and Translational Research. Translational Gastroenterology. Academic Press, pp. 175–177.

Mengist, W., Soromessa, T., Feyisa, G.L., 2024. Monitoring Afromontane forest cover loss and the associated socio-ecological drivers in Kaffa biosphere reserve, Ethiopia. Trees For. People 6, 100161.

Moors, E.J., Groot, A., Biemans, H., van Scheltinga, C.T., Siderius, C., Stoffel, M., Huggel, C., Wiltshire, A., Mathison, C., Ridley, J., Jacob, D., Kumar, P., Bhadwal, S., Gosain, A., Collins, D.N., 2011. Adaptation to changing water resources in the Ganges basin, northern India. Environ. Sci. Pol. 14 (7), 758–769.

Nandi, S., Gonela, V., 2022. Rainwater harvesting for domestic use: a systematic review and outlook from the utility policy and management perspectives. Util. Policy 77, 101383.

Navarro, N., Moreno, V., Scott, C., 2017. Ocial networks for management of water scarcity: evidence from the San Miguel Watershed, Sonora, Mexico. Water Altern. (WaA) 10 (1), 134–155.

Nega, T.A., Alemu, B.A., Kassie, K.E., 2025. Adaptation practices of smallholder farmers to climate variability: evidence from three agroecological zones in northwestern Ethiopia. Curr. Res. Environ. Sustain. 10, 100305.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa. In: Barros, V.R., et al. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Cambridge University Press, pp. 1199–1265.

Nimma, D., Devi, O.R., Laishram, B., Ramesh, J.V.N., Boddupalli, S., Ayyasamy, R., Tirth, V., Arabi, A., 2025. Implications of climate change on freshwater ecosystems and their biodiversity. Desalination Water Treat. 321, 100889.

Nguyen, T., Tran, V., 2023. Environmental policy compliance in Vietnam: joint decisions on pollution control technologies. Environ. Econ. Pol. Stud. 25 (3), 456–478.

Ofori, S.A., Cobbina, S.J., Obiri, S., 2021. Climate change, land, water, and food security: perspectives from Sub-Saharan Africa. Front. Sustain. Food Syst. 5, 680924.

Ojo, T.O., Adetoro, A.A., Ogundeji, A.A., Belle, J.A., 2021. Quantifying the determinants of climate change adaptation strategies and farmers' access to credit in South Africa. Sci. Total Environ. 792, 148499.

Olmstead, S.M., 2014. Climate change adaptation and water resource management: a review of the literature. Energy Econ. 46, 500–509.

Oumer, A., Burton, M., Kassie, M., 2025. Dynamics of multiple sustainable agricultural intensification practices adoption: application of the intertemporal multivariate probit model. PLoS One 20 (1), 1–17.

Perga, E.-E., Sarrasin, O., Steinberger, J., Lane, S.N., Butera, F., 2023. The climate change research that makes the front page: is it fit to engage societal action? Glob. Environ. Change 80, 102675.

Ricart, S., Gandolfi, C., Castelletti, A., 2025. What drives farmers' behavior under climate change? Decoding risk awareness, perceived impacts, and adaptive capacity in northern Italy. Heliyon 11 (1), e41328.

Ringler, C., Agbonlahor, M., Barron, J., Baye, K., Meenakshi, J.V., Mekonnen, D.K., Uhlenbrook, S., 2022. The role of water in transforming food systems. Global Food Secur. 33, 100639.

Rosenthal, S., 2022. Information sources, perceived personal experience, and climate change beliefs. J. Environ. Psychol. 81, 101796.

Rout, C., Sharma, A., 2024. Bridging the gap: exploring adaptation strategies for climate-resilient agriculture and enhanced livelihoods in Odisha. Clim. Environ. Agricul. Develop. 57–74.

Shah, F., Sharifi, A., 2025. Climate models for predicting precipitation and temperature trends in cities: a systematic review. Sustain. Cities Soc. 120, 106171.

Saha, M., Biswas, A., Faisal, M., Meandad, J., Ahmed, R., Prokash, J., Saki, F., 2019. Factors affecting to adoption of Climate-smartAgriculture practices by coastal Farmers'in Bangladesh. Am J. Environ. Sustain. Develop. 4 (4), 113–121.

Seaman, J., Sawdon, G., Acidri, J., Petty, C., 2014. The household economy approach. Managing the impact of climate change on poverty and food security in developing countries. Clim. Risk Manag. 4–5, 59–68.

Sheikh, Z.A., Ashraf, S., Weesakul, S., Ali, M., Hanh, N.C., 2024. Impact of climate change on farmers and adaptation strategies in Rangsit, Thailand. Environ. Chall. 15, 100902.

Shiferaw, B., Holden, S., Lunduka, R., 2014. Adoption and impact of improved maize varieties on household food security in eastern Ethiopia. Food Policy 46, 31–43.

Tefera, G.W., Dile, Y.T., Srinivasan, R., Baker, T., Ray, R.L., 2023. Hydrological modeling and scenario analysis for water supply and water demand assessment of Addis Ababa city, Ethiopia. J. Hydrol.: Reg. Stud. 46, 101341.

Tofu, D., Woldeamanuel, T., Haile, F., 2022. Smallholder farmers' vulnerability and adaptation to climate change induced shocks: the case of Northern Ethiopia highlands. J. Agric. Food Res. 8, 100312.

Touch, V., Tan, D.K.Y., Cook, B.R., Liu, D.L., Cross, R., Tran, T.A., Utomo, A., Yous, S., Grunbuhel, C., Cowie, A., 2024. Smallholder farmers' challenges and opportunities: implications for agricultural production, environment and food security. J. Environ. Manag. 370, 122536.

Vallino, E., Ridolfi, L., Laio, F., 2020. Measuring economic water scarcity in agriculture: a cross-country empirical investigation. Environ. Sci. Pol. 114, 73–85.

Van, A., Holvoet, N., 2016. A gender approach to understanding the differentiated impact of barriers to adaptation: responses to climate change in rural Ethiopia. Reg. Environ. Change 16 (6), 1701–1713.

Vema, V., Sudheer, K.P., Chaubey, I., 2018. Hydrologic design of water harvesting structures through simulation-optimization framework. J. Hydrol. 563, 460–469.

Worqlul, A.W., Dile, Y.T., Ayana, E.K., Jeong, J., Adem, A.A., Gerik, T., 2018. Impact of climate change on streamflow hydrology in headwater catchments of the upper Blue Nile Basin, Ethiopia. Water 0 (2), 120.

Wang, H., Zhang, L., 2024. Health service utilization among aging populations: interdependent choices in urban China. Soc. Sci. Med. 340, 116–124.

Yamane, T., 1967. Statistics: an Introductory Analysis, second ed. Harper and Row, New York.

Zhang, Q., Chen, G., Tam, K.-P., 2025. Climate change information seeking: a scoping review. J. Environ. Psychol. 106, 102742.

Zhang, Y., Barten, P.K., 2009. Watershed Forest Management Information System (WFMIS). Environ. Model. Software 24 (4), 569–575.

Zahnow, R., Yousefnia, A.R., Hassankhani, M., Cheshmehzangi, A., 2025. Climate change inequalities: a systematic review of disparities in access to mitigation and adaptation measures. Environ. Sci. Pol. 165, 104021.

Zeleke, T., Beyene, F., Deressa, T., Yo usuf, J., Kebede, T., 2021. Vulnerability of smallholder farmers to climate change-induced shocks in East Hararghe Zone, Ethiopia. Sustainability 13 (4), 2162.

Ntsoane, M.M., Ndoro, J.T., Wayi-Mgwebi, N., 2025. Multivariate Probit Model Analysis of the Factors Influencing Smallholder Farmers' Choice of ICT Tools: A Case Study of Mpumalanga, South Africa. Agriculture.15, 1817.

Pahl-Wostl, C., Arthington, A., Bogardi, J., Bunn, S.E., Hoff, H., Lebel, L., Nikitina, E., Palmer, M., Poff, L.N., Richards, K., Schlüter, M., Schulze, R., St-Hilaire, A., Tharme, R., Tockner, K., Tsegai, D., 2013. Environmental flows and water governance: managing sustainable water uses. Curr. Opin. Environ. Sustain. 5 (3–4), 341–351.

Yu, Y., Yan, J., Akin, Su-M., Liu, H., Martens, P., 2025. Livestock diversification works as a helpful livelihood strategy for herders on the Tibetan Plateau: Implications for climate change adaptation, Sustainable Futures.10,101116.