

# Constraints to Climate Change Adaptation among Smallholder Farmers in the Oti River

Osman Zakari

ozakari82@gmail.com

University of Energy and Natural Resources

Caleb Mensah

University of Energy and Natural Resources

Naomi Kumi

University of Energy and Natural Resources

Ebenezer Boakye

Takoradi Technical University

Samuel Ofosu Anim

Koforidua Technical University

Bernard Baatuuwie

University for Development Studies

Emmanuel Nouwati

Kwame Nkrumah University of Science and Technology

---

## Research Article

**Keywords:** Climate change, Variability, Adaptation, Constraints, Smallholder farmers, Oti River Basin

**Posted Date:** September 22nd, 2026

**DOI:** <https://doi.org/10.21203/rs.3.rs-10879664/v1>

**License:** © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

**Additional Declarations:** No competing interests reported.

---

# Abstract

The Oti River Basin (ORB) continues to witness recurrent floods and droughts, with smallholder farmers often vulnerable to these impacts. The specific constraints in the ORB remain poorly understood due to its unique transboundary characteristics. This study examined the constraints to climate change adaptation among smallholder farmers in the basin. Specifically, it (i) determined the patterns of rainfall and temperature in the ORB between 1995 and 2025, (ii) assessed the impacts of climate change on smallholder farmers in the basin, and (iii) identified the adaptation strategies among smallholder farmers in the basin. Climate datasets were obtained from the Ghana Meteorological Agency (GMet) and supplemented with Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). Questionnaires were administered to 300 smallholder farmers to assess the constraints and the factors influencing the adaptation strategies. Mann–Kendall (MK) test and Sen’s estimator were used to analyze rainfall and temperature trends in the basin, while the Ordinary Least Squares Regression (OLS) model was used to assess the adaptation constraints. The results showed weak interannual variability in rainfall ( $p = 0.5633$ ) and temperature ( $p = 0.2920$ ), with both showing a slight increasing trend over the study period. Livelihood diversification, improved seed varieties, crop diversification, irrigation, and agroforestry were identified as the most adopted strategies by farmers in the basin. Irrigation technology was the most effective adaptation strategy by farmers, though its adoption remained low due to financial constraints, inadequate infrastructure, and limited institutional support. The major constraints to adaptation strategies by farmers were financial, information and knowledge gaps, institutional limitations, extension services, and policy and governance issues. Climate information systems, credit access, irrigation infrastructure, extension services, and gender-responsive policies are essential for building climate-resilient agricultural systems in the basin.

## Key highlights

- Oti River Basin is an agrarian basin with multiple climate hazards, such as droughts and floods, that threaten agricultural productivity.
- The common adaptation strategies among smallholder farmers include livelihood diversification, improved seeds, and crop diversification.
- Key constraints to climate change adaptation are economic barriers
- Adaptation capacity of smallholder farmers are influenced by financial, access to extension services, farm size, gender, and age.
- Access to credit, climate information, irrigation, and institutional strengthen climate resilience among smallholder farmers.

## 1. Introduction

Climate change (CC) is arguably one of the most pressing environmental challenges confronting countries, with far-reaching consequences on ecosystems, livelihoods, and human health (Beckline et al.,

2025; Biswas et al., 2020). The impacts of climate change are pronounced in rural and coastal communities due to their limited financial resources and adaptive capacity (Zothanzama et al., 2025). West Africa is highly vulnerable to the impacts of CC because of the widespread poverty, limited technological capacity, economic instability, inadequate agricultural policies, and over-reliance on rain-fed agricultural systems (Naazie et al., 2023). The agricultural sector remains one of the most vulnerable to the impact of CC as a result of the over-reliance of farmers on rain-fed agricultural practices coupled with low levels of technology and input support systems (Arhin, 2022). Agriculture contributes significantly to the economies of West Africa, with 62% of the population directly engaged in the sector for socioeconomic and livelihood support systems (Koffi et al., 2023).

The effects of CC in Ghana are manifested through ecological, human, and socio-economic systems, with riparian communities highly vulnerable to the impact because of their heavy reliance on climate-sensitive resources (Osman et al., 2025). As a result, these areas are predisposed to floods that destroy crops, property, and human lives (Abungba et al., 2022; Tengapoe et al., 2023). In Northern Ghana, temperatures are expected to increase by 2.1–2.4°C by 2050, compared to 1.7–2.0°C in the forest zone and 1.3–1.6°C in the transitional zone (Arfasa et al., 2024; Pabi et al., 2021). Given these trends, a critical question that remains unanswered is whether the riparian communities are adequately prepared to confront and adapt to these growing climate threats.

The Oti River Basin (ORB) is exposed to climate-induced hazards such as floods, erosion, droughts, and poor water quality (Ampim et al., 2021). These impacts not only threaten socioeconomic wellbeing but also disrupt local food systems, social cohesion, and public health (Mwinkom et al., 2021). In recent years, the basin has experienced significant hydrological challenges characterized by floods and drought, destroying farmlands, crops, and property, with sections of the river drying particularly during the dry seasons (Dembélé et al., 2022). Additionally, fluctuations in water quality have been observed, raising serious water quality issues for both domestic and agricultural purposes (Mwanga et al., 2024).

Despite the growing evidence on climate variability in Ghana, limited evidence exists on the determinants of adaptation constraints among farmers in the ORB. For instance, studies by Fagariba et al. (2018), Gyimah et al. (2020), and Issaka et al. (2023) identified financial, institutional, extension, information, and socioeconomic barriers to climate adaptation. Similarly, Awuni et al. (2023) and Alidu et al. (2022) also identified education and access to extension services as important factors influencing farmers' CC adaptation practices in northern Ghana. However, these studies fail to establish the contribution of these constraints, their variation across farmer groups, and the socioeconomic and institutional factors associated with greater constraint levels, particularly within the ORB. Additionally, most of these studies failed to translate the multiple constraints identified into differentiated interventions that address the specific barriers faced by farmer groups. It therefore remains unclear which constraints are most influential and which farmer characteristics and institutional conditions are associated with greater adaptation constraints in the basin. Addressing this gap is important for developing targeted, context-specific, and inclusive adaptation strategies that address the most consequential barriers to climate adaptation among smallholder farmers in the ORB.

This study seeks to examine the Spatio-temporal trend of rainfall and temperature and identify the constraints of climate change adaptation strategies among smallholder farmers in the ORB. Specifically, the study (i) determined the spatio-temporal patterns of rainfall and temperature in the Oti River Basin (1995–2025), (ii) assessed the impacts of climate change among smallholder farmers in the basin, (iii) identified the adaptation strategies among smallholder farmers in the basin, and (iv) assessed the key constraints to climate change adaptation in the basin. This study provides a comprehensive understanding of the social, economic, cultural, and environmental factors that shape adaptation strategies in the basin. It will also inform climate policy development programs in Ghana and advance the understanding of the key drivers and constraints affecting CC adaptation actions among riparian communities.

## 2. Materials and Methods

### 2.1 Study area

The ORB is a transboundary river basin shared by four riparian countries (Benin, Burkina Faso, Togo, and Ghana), is located between longitude 10°50' N and latitude 7°30' N (Fig. 1), with an area of  $\approx 17,942 \text{ km}^2$  and a length of about 936.7 km. In Ghana, it passes through the North-East, Northern, and Oti regions, and traverses the East Mamprusi, Gushigu, Cheroponi, Saboba, Yendi, Zabzugu, Nanumba North and South, Kpandai, Krachi East and West districts (Ampadu, 2017).

The basin has a unimodal rainfall pattern with mean rainfall ranging from 1,000 to 1,300 mm, and characterized by a prolonged dry period with harmattan and high temperatures, ranging from 24.4°C to 43°C. The major soil types in the basin are Ochrosols, Acid Gleisols, Savannah Ochrosols, and Groundwater Laterites (Ampadu, 2017; Ampofo et al., 2022). Vegetation type is largely savannah woodland with scattered, fire-resistant tree species including shea (*Vitellaria paradoxa*), dawadawa (*Parkia biglobosa*), baobab (*Adansonia digitata*), neem (*Azadirachta indica*), kapok (*Ceiba pentandra*), silk cotton (*Bombax costatum*), and Tamarind (*Tamarindus indica*). The major land cover types in the basin include savannah forest, grasslands, cropland, built-up areas, bare lands, and water bodies (Ampofo et al., 2022; Mwinkom et al., 2021).

The key economic activity is agriculture and related activities, with maize, millet, sorghum, rice, yams, cassava, and vegetables being the major crops cultivated by farmers in the basin (Ghana Statistical Service, 2021). Other livelihood activities in the area are livestock rearing and fishing, agro-based enterprises including shea butter and dawadawa processing, rice milling, and soap making (Alhassan, 2019). The dominant ethnic groups in the basin include Mamprusi, Dagombas, Nanumba, Cherkosi, and Konkomba (Azumah et al., 2022; Bitasse et al., 2020).

### 2.2 Research Methods and Design

#### 2.2.1 Research design

This study adopted a mixed-methods approach to capture both quantitative and qualitative datasets. This approach provides a comprehensive understanding of adaptation practices, challenges, and perceptions among smallholder farmers. Quantitative data were collected through structured household surveys and face-to-face interviews to measure the adaptation strategies and perceived barriers to climate change adaptation. While qualitative data were also gathered through key informant interviews (KIIs) and focus group discussions (FGDs). These techniques provided insights into the socio-cultural, institutional, gender dynamics, and environmental factors influencing adaptation strategies in the basin.

## 2.2.2 Sampling procedure and respondent characteristics

The basin was divided into three sections (upstream, midstream, and downstream) with communities selected from each section. The sample size for the study was determined using equations 1, and 2.

$$n = N / (1 + N (e^2)) \dots\dots\dots \text{equation 1}$$

$$nr = (RPS) / N \times n \dots\dots\dots \text{equation 2}$$

Where n is the sample size of the population, N is the population size, e is the margin of error at a 95% confidence interval, nr is the sample size of respondents, and RPS is the respondent population size (Sadiq et al., 2019; Yahaya et al., 2023).

Table 1  
Sample size for communities used in the study

| Name of community | Number of households | Sample size |
|-------------------|----------------------|-------------|
| Kudani Bakanu     | 540                  | 16          |
| Bukasu            | 283                  | 9           |
| Sabare No.2       | 1009                 | 30          |
| Ojoja A           | 563                  | 17          |
| Salinayili        | 1420                 | 43          |
| Battorya          | 420                  | 13          |
| Opijua            | 1285                 | 17          |
| Jimam Ponayili    | 407                  | 12          |
| Nasande           | 1246                 | 53          |
| Bladjai           | 2812                 | 84          |
| Total             | 9,935                | 300         |

The communities were selected based on proximity to riverbanks, making them vulnerable to climate hazards such as floods, erosion, and prolonged drought (Gyimah et al., 2024). A total of 300

questionnaire were administered to respondents, with 220 household interviews, 50 KIIs, and 30 FGDs (Table 1). Out of this, 65% of respondents were male, and 35% were female. The interviews took place between 12th January and 12th March 2026. Key informants were selected from smallholder farmers, farmer-based organizations (FBOs), opinion leaders, and representatives of relevant institutions, including community-based organizations, the District Assembly (DA), Department of Agriculture, Religious bodies, the Forestry Services Commission (FSC), Water Resource Commission (WRC), and the Environmental Protection Authority (EPA).

Simple random and purposive sampling techniques were used for the household surveys, KIIs, and FGDs. Purposive sampling technique ensured the inclusion of respondents with relevant knowledge and experience, while simple random sampling ensured representative of the samples. Data from the KIIs and FGDs were used to triangulate the responses from the household surveys and provide a more comprehensive understanding of the adaptation strategies among respondents in the basin. The selection was purposively done by virtue of the respondents' in-depth knowledge or direct involvement in farming activities. Six FGDs were held, with each consisting of 5–15 participants. Participants were purposively selected from various stakeholder groups, including farmers, fishers, opinion leaders, youth leaders, and commercial charcoal producers. The selection and composition of FGDs were guided by the knowledge and expertise of respondents in the agricultural activities of the area(Alhassan et al., 2019).

### 2.2.3 Data analysis

Frequencies, percentages, means, and standard deviations were computed for all socio-demographic, perception, impact, adaptation, and constraint variables. Internal consistency of the two composite scales was assessed using Cronbach's alpha (Eq. 3)

$$\alpha = [k / (k - 1)] \times [1 - (\sum \sigma^2_i / \sigma^2_{\Sigma})] \dots\dots\dots \text{equation 3}$$

where k is the number of items in the scale,  $\sigma^2_i$  is the variance of item i, and  $\sigma^2_{\Sigma}$  is the variance of the total scale score. Values of  $\alpha \geq 0.70$ , interpreted as acceptable and  $\geq 0.80$  as good (Nunnally, 1978); the Climate Impact Scale ( $\alpha = 0.873$ ) met the “good” threshold, and the adaptation constraint scale ( $\alpha = 0.683$ ) falls within the acceptable threshold (Sun et al., 2021; Wang and He, 2026). While the differences in the composite constraint index across various independent groups were computed with Eq. 4

$$H = [12 / (N (N + 1))] \times \sum_j \left( R_j^2 / n_j \right) - 3 (N + 1) \dots\dots\dots \text{equation 4}$$

where N is the total sample size, k is the number of groups,  $n_j$  is the number of observations in group j, and  $R_j$  is the sum of ranks across the samples in group j. H is approximately chi-square distributed with k – 1 degrees of freedom. The bivariate associations between the constraint index and socioeconomic variables were determined using Eq. 5.

#### 2.2.3.1 Ordinary Least Squares Regression Model

To determine the joint determinants of constraint severity, a multiple linear regression model was used with the composite constraint index as the continuous dependent variable (Eq. 5)

$$Y_i = \beta_0 + \beta_1 \text{Age}_i + \beta_2 \text{Exp}_i + \beta_3 \text{Size}_i + \beta_4 \text{HH}_i + \beta_5 \text{Edu}_i + \beta_6 \text{Gen}_i + \beta_7 \text{Ext}_i + \beta_8 \text{Cred}_i + \beta_9 \text{Info}_i + \beta_{10} \text{Train}_i + \beta_{11} \text{Impact}_i + \varepsilon_i \dots \text{Eq. 5}$$

where  $Y_i$  is the composite constraint index for farmer  $i$ ; the right-hand-side variables are, respectively, age, farming experience, farm size, household size, education level, gender (1 = male), extension access, credit access, climate information access, training received, and the climate impact index.  $\varepsilon_i$  is the idiosyncratic error term (Bismark et al., 2021; Gashaw et al., 2018)

## 2.2.4 Climate data

Rainfall and temperature datasets for 1995–2025 were acquired from the Ghana Meteorological Agency (GMET) stations at Yendi and Gambaga, and complemented by data from the Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) dataset. The satellite data were bias-corrected using data from GMET to improve accuracy and reliability. This is consistent with the results of Gyimah et al. (2024), who established the strong capability of CHIRPS data to reproduce the basin's climatological characteristics. Quality control checks revealed that missing observations accounted for less than 5% of both rainfall and temperature data, which indicated the dataset was suitable for long-term climate analysis.

### 2.2.4.1 Spatial distribution and trend analysis of rainfall and temperature

The Mann–Kendall (MK) test was used to determine the significance of rainfall and temperature trends. The test is suitable for this study because the data points are not homogeneously distributed, and it is used to determine increasing or decreasing trends and to determine whether the trend is statistically significant (Arfasa et al., 2024). The model is robust and exhibits low sensitivity to abrupt breaks, and is very sensitive to outliers (Suabir et al., 2021; Tan et al., 2015). It is computed using equations 6 and 7.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n-1} \text{sgn}(x_j - x_i) \dots \text{Eq. 6}$$

$$\text{sgn}(X_j - X_k) = \begin{cases} +1, & \text{if } x_j - x_k > 0 \\ 0, & \text{if } x_j - x_k = 0 \\ -1, & \text{if } X_j - X_k < 0 \end{cases} \dots \text{equation 7}$$

where  $x_j$  and  $x_k$  denote data points in periods  $j$  and  $k$ . While the number of data series is larger than or equal to 10 ( $n \geq 10$ ), the M–K test is categorized by a standard distribution with the mean  $E(S) = 0$  and variance  $\text{Var}(S)$ , expressed using Eq. 11 (Girma et al., 2023).

$$\text{Var}(s) = \frac{n(n-1)(2n+5) - \sum_{p=1}^g tp(tp-1)(2tp+5)}{18} \dots \text{Eq. 8}$$

where  $n$  = number of observations in the time series;  $g$  = number of tied groups;  $tp$  = number of observations in the  $p^{\text{th}}$  tied group (Arfasa et al., 2024). The standardized test statistic ( $Z$ ) is computed using Eq. 9.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(s)}}, & S > 0, \\ 0, & S = 0, \\ \frac{S+1}{\sqrt{\text{Var}(s)}}, & S < 0. \end{cases} \dots\dots\dots \text{equation 9}$$

The magnitude of the trend was determined using Sen's slope estimator and computed with Eq. 10. The trend analysis was computed at a 0.05 significance level, where a  $p$ -value  $\leq 0.05$  indicates a significant trend, and a  $p$ -value  $> 0.05$  indicates a non-significant trend (Arfasa et al., 2024; Kassaye et al., 2024).

$$Q_i = \frac{X_j - X_k}{j - k}, \text{ for } i = 1, 2, \dots, N \dots\dots\dots \text{equation 10}$$

where  $x_j$  and  $x_k$  are data points at time  $j$  and ( $j > k$ ). When there is only a single datum at each time,  $N$  is given as time periods,  $n$  is the total number of observations (Girma et al., 2023). The  $N$  values of slope estimator are arranged from smallest to largest, and the median of the slope ( $\beta$ ) is computed as follows

$$Q_{\text{med}} = \begin{cases} Q\left(\frac{N+1}{2}\right), & \text{if } N \text{ is odd,} \\ Q\left(\frac{N}{2}\right) + Q\left(\frac{N}{2} + 1\right), & \text{if } N \text{ is even.} \end{cases} \dots\dots\dots \text{equation 11}$$

Where  $Q_{\text{med}}$  is the Sen slope estimator;  $Q(i)$  = the  $i^{\text{th}}$  ordered slope after arranging all slopes in ascending order.  $Q_{\text{med}} > 0$ : Increasing trend,  $Q_{\text{med}} < 0$ : Decreasing trend, and  $Q_{\text{med}} = 0$ : No trend (Frimpong et al., 2023; Malede et al., 2023).

### 3. Results and Discussion

#### 3.1 Spatio-temporal analysis of rainfall and temperature in the basin.

##### 3.1.1 Analysis of temperature trend in the basin

The annual temperature from 1995 to 2025 (Fig. 2) in the basin reveals a slight increasing trend of  $0.0108^\circ\text{C yr}^{-1}$  ( $0.108^\circ\text{C decade}^{-1}$ ). Sen's slope estimator revealed a positive rate of change of  $0.0116^\circ\text{C yr}^{-1}$  ( $0.116^\circ\text{C decade}^{-1}$ ). The linear regression analysis ( $p = 0.2813$ ) and Mann–Kendall test ( $Z = 1.054$ ,  $p = 0.2920$ ) indicated the observed warming trend was not statistically significant at the 95% C.I. There was considerable interannual temperature variability, ranging from  $27.19^\circ\text{C}$  in 2006 to  $29.0^\circ\text{C}$  during the

study period. Despite the weak trend, the relative higher temperature values observed could suggest a gradual warming trend in the basin. This observation is consistent with the findings of Ampadu (2017) and Suabir et al. (2021) in the ORB, who reported increasing trends but statistically insignificant results. Similar patterns were also observed by Ampadu (2023) and Gabiri et al. (2020) in northern Ghana and parts of Africa. The observed temperature changes may be ascribed to changing rainfall patterns and LULC changes, deforestation, and anthropogenic activities.

The conversion of forest and grassland to cropland and built-up areas may alter surface energy balances, resulting in higher land surface temperatures and localized warming. This observation is consistent with similar findings by Awotwi et al. (2015) in the ORB, who reported a high conversion rate of dense savannah forest to other LULC types. Despite the weak warming trend, its implications may result in increases in temperature, resulting in increased evapotranspiration rates, reduced soil moisture content, and increased crop water requirements. It is also important to note that even the modest temperature increases could adversely affect agricultural productivity, water security, and ecosystem resilience.

### **3.1.2 Spatial distributions of rainfall in the basin**

Annual rainfall in the basin (Fig. 3) revealed significant interannual variability, ranging from 770mm to 1,450mm, with an overall trend depicting a slight increase in annual rainfall over the study period. The analysis further revealed a weak increasing trend of 2.55 mm yr<sup>-1</sup> (25.5 mm decade<sup>-1</sup>), while Sen's slope estimator indicated an increase of 2.89 mm yr<sup>-1</sup> (28.9 mm decade<sup>-1</sup>). However, the trend was not statistically significant by the regression analysis ( $R^2 = 0.016$ ,  $p = 0.4980$ ) and the Mann–Kendall test ( $Z = 0.578$ ,  $p = 0.5633$ ), and may be attributed to climatic and LULC changes. Annual rainfall exhibited marked variability throughout the study period, ranging from 770 mm in 2002 to 1,400 mm in 2008 and 2025. The moving-average analysis portrayed alternating wet and dry phases with no sustained long-term increase or decrease in the rainfall pattern. These results suggest rainfall variability, rather than a significant long-term trend in annual rainfall. This constitutes the dominant hydro-climatic characteristic of the basin with implications for agricultural production, water availability, and ecosystem function.

## **3.2 Socio-demographic characteristics of respondents**

The socio-demographic characteristics of the respondents (Table 2) revealed that female respondents were 25.3%, while males 74.7%, with the mean age of the respondents of 48 years. The results revealed that 74.7% of women were married, while 19.0% were widowed. The distribution of marital status suggests potential differences in vulnerability among female-headed households. This observation is in line with similar findings by Gyimah et al. (2024), who reported that women faced greater vulnerability compared to their male counterparts. The educational level of respondents was relatively high, with 37.7% completing Senior High School (SHS), 31.0% tertiary education, and 6.3% no formal education. The average farming experience was 21 years, and the average farm size was 10.3 acres. These household dynamics may have implications for labour availability, resource allocation, and households' capacity to respond to climate-related risks.

Table 2  
Socio-demographic characteristics of respondents

| Demographic characteristics | Group                        | Frequency (n) | Percentage (%) |
|-----------------------------|------------------------------|---------------|----------------|
| Age (years)                 | 25–34                        | 46            | 15.3           |
|                             | 35–44                        | 75            | 25.0           |
|                             | 45–54                        | 79            | 26.3           |
|                             | 55 and above                 | 100           | 33.3           |
| Farm experience (years)     | Less than 5                  | 18            | 6.0            |
|                             | 5–10                         | 56            | 18.7           |
|                             | 11–20                        | 95            | 31.7           |
|                             | More than 20                 | 131           | 43.7           |
| Farm size (acres)           | 1–5                          | 130           | 43.3           |
|                             | 6–10                         | 56            | 18.7           |
|                             | 11–20                        | 76            | 25.3           |
|                             | 21–50                        | 38            | 12.7           |
| Household size (persons)    | 1–4                          | 18            | 6.0            |
|                             | 5–8                          | 207           | 69.0           |
|                             | 9–12                         | 19            | 6.3            |
|                             | 13 and above                 | 56            | 18.7           |
| Gender                      | Male                         | 224           | 74.7           |
|                             | Female                       | 76            | 25.3           |
| Education                   | No formal education          | 19            | 6.3            |
|                             | Primary                      | 38            | 12.7           |
|                             | Junior High School           | 37            | 12.3           |
|                             | Senior High School           | 113           | 37.7           |
|                             | Tertiary                     | 93            | 31.0           |
| Topography of farm          | Upland                       | 129           | 43.0           |
|                             | Floodplain                   | 57            | 19.0           |
|                             | Both (upland and floodplain) | 114           | 38.0           |
| Extension access            | Yes                          | 149           | 49.7           |

| Demographic characteristics | Group      | Frequency (n) | Percentage (%) |
|-----------------------------|------------|---------------|----------------|
| Credit access               | No         | 151           | 50.3           |
|                             | Yes        | 149           | 49.7           |
|                             | No         | 151           | 50.3           |
| Source of water             | Rain-fed   | 281           | 93.7           |
|                             | Irrigation | 19            | 6.3            |
| Crop yield (last 5 years)   | Increasing | 93            | 31.0           |
|                             | Stable     | 113           | 37.7           |
|                             | Decreasing | 94            | 31.3           |

. The result suggests a diversified livelihood system, where households are not dependent on a single economic activity. With 37.3% of the respondents working in the civil service, 31.3% are full-time farmers, and 25.0% are traders. This has implications for adaptive capacity and resilience, especially to climate and environmental stresses in the basin. Though civil service employment may buffer some households against environmental shocks, the dependence on farming activities by the majority in the basin implies that the majority of the population remains exposed to climate and environmental risks. It is also interesting to note that respondents reported varied views on crop yields over the last 5 years, with 31% of the respondents reporting a decline in yields, 37.7% a stable performance, and 31.0% improved yields. The differences in yield may be due to local environmental conditions, access to resources, adaptation practices, and farm management strategies.

### 3.3 Climate change perception among respondents

Respondents also reported that they have observed changes in the climate system in the area over the past years (Table 3). With the key visible changes including increase in pests and diseases (31.7%), drought (31.0%), increased temperatures (18.7%), erratic rainfall (12.7%), and flooding (6.0%). The high incidence of pests and diseases in the area may be attributed to the combined effects of rising temperatures and moisture stress, which create favourable conditions for pest proliferation and weaken crop resistance.

Table 3  
Climate change perception by respondents in the basin

| Variable                                   | Frequency | Percentage (%) |
|--------------------------------------------|-----------|----------------|
| <b>Climate Change Over the Past Decade</b> |           |                |
| Yes                                        | 300       | 100.0          |
| <b>Observed climate change</b>             |           |                |
| Pest and disease intensification           | 95        | 31.7           |
| Drought                                    | 93        | 31.0           |
| Increased temperatures                     | 56        | 18.7           |
| Erratic rainfall                           | 38        | 12.7           |
| Flooding                                   | 18        | 6.0            |
| <b>Severity of Climate Change</b>          |           |                |
| Very High                                  | 92        | 30.7           |
| High                                       | 95        | 31.7           |
| Moderate                                   | 76        | 25.3           |
| Low/Very Low                               | 37        | 12.3           |

The impact severity among respondents was assessed, with 30.7% reporting very high, 31.7% high, 25.3% moderate, and 12.3% low impact. The proportion of respondents reporting high and very high severity was 62.3%, suggesting that a majority of respondents in the basin perceive climate impacts as significant and directly affecting their livelihoods. These findings are consistent with Azumah et al. (2021), who reported high perceived severity of CC impacts among farmers in the Zabzugu and North Tongu districts of Ghana.

### 3.4 Impacts of climate change on agriculture and livelihood

The effects of CC on agriculture and livelihood were assessed (Table 4). Food insecurity recorded the highest mean score of 3.50, water scarcity 3.00, drought 2.89, and reductions in crop yield 2.88. These findings align with those of Suabir et al. (2021) and Alhassan et al. (2025), who attributed these challenges to erratic rainfall and prolong drought. The overall impact index of 2.85 indicates a moderate-to-high level of climate impacts in the basin, with food insecurity being the key critical livelihood constraint. This result aligns with similar findings byKangah & Atampugre (2022) in Ghana, who also reported similar results.

Table 4  
Climate impacts on agriculture and livelihoods

| Impact Indicator                                                                                                                                     | Mean        | SD          | Rank     |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|----------|
| <b>Agricultural Impacts</b>                                                                                                                          |             |             |          |
| Crop yield reduction                                                                                                                                 | 2.88        | 1.06        | 3        |
| Crop failure                                                                                                                                         | 2.87        | 1.21        | 4        |
| Livestock loss                                                                                                                                       | 2.80        | 0.99        | 8        |
| Soil fertility decline                                                                                                                               | 2.75        | 1.03        | 10       |
| <b>Environmental Impacts</b>                                                                                                                         |             |             |          |
| Flooding damage                                                                                                                                      | 2.77        | 1.25        | 9        |
| Drought stress                                                                                                                                       | 2.89        | 1.22        | 2        |
| Water scarcity                                                                                                                                       | 3.00        | 0.93        | 2        |
| Soil erosion                                                                                                                                         | 2.75        | 1.25        | 10       |
| <b>Socioeconomic Impacts</b>                                                                                                                         |             |             |          |
| Income reduction                                                                                                                                     | 2.80        | 1.28        | 8        |
| Food insecurity                                                                                                                                      | 3.50        | 1.00        | 1        |
| Asset loss                                                                                                                                           | 2.81        | 1.07        | 7        |
| Migration pressure                                                                                                                                   | 2.49        | 1.45        | 12       |
| <b>Overall Impact Index</b>                                                                                                                          | <b>2.85</b> | <b>0.79</b> | <b>—</b> |
| <b>Note: Scale: 1 = No impact, 2 = Low impact, 3 = Moderate impact, 4 = High impact, 5 = Very High impact. Cronbach <math>\alpha</math> = 0.873.</b> |             |             |          |

## 3.6 Adaptation strategies among respondents

Climate change awareness and adaptation among respondents were widespread, with the majority of them reporting the adoption of at least one adaptation strategy (Table 6). The most adopted strategies were livelihood diversification (56.0%), improved seed varieties (50.0%), and crop diversification (43.7%). Thirty-one percent (31.0%) of the respondents reported adopting irrigation and agroforestry strategies, with soil conservation practices (18.7%) and migration (18.7%) being the least frequently adopted strategies.

Table 5  
Adaptation strategies among respondents in the basin

| Adaptation Strategy                  | Frequency(n) | Percentage (%) | Rank |
|--------------------------------------|--------------|----------------|------|
| Livelihood diversification           | 168          | 56.0           | 1    |
| Improved seed varieties              | 150          | 50.0           | 2    |
| Crop diversification                 | 131          | 43.7           | 3    |
| Irrigation                           | 93           | 31.0           | 4    |
| Agroforestry                         | 93           | 31.0           | 4    |
| Soil conservation                    | 56           | 18.7           | 6    |
| Migration                            | 56           | 18.7           | 6    |
| Mean strategies per farmer (SD)      | 2.49 (1.65)  |                |      |
| High adopters ( $\geq 3$ strategies) | 93           | 31.0           |      |

The results also revealed that 31.0% of respondents are classified as high adopters, having implemented three or more strategies. The results further revealed that farmers in the ORB tend to favour low-cost and less resource-intensive strategies, such as livelihood and crop diversification, over more capital and technology-intensive options, including irrigation and agroforestry. The finding is consistent with the results of Chima et al. (2024) in Nigeria and Guodaar and Asante (2018) in Ghana, who reported that most farmers adopt strategies with minimal technological inputs and financial investment.

### 3.8 Effectiveness of adaptation strategies among respondents

The effectiveness of adaptation strategies being implemented by farmers was assessed (Table 6), with irrigation being the most effective adaptation strategy despite its low adoption rate; those who had access to it perceived it as highly effective in reducing climate-related risks and improving agricultural productivity. These results align with those of Roth et al. (2019) and Kolekar et al. (2021), who reported similar results in South Asia and India. Livelihood diversification was reported by farmers as the second-most-adopted strategy, providing an important buffer against climate-induced agricultural uncertainties. This supports households to reduce their dependence on farming income and enhances their capacity to withstand climatic shocks. The result is consistent with the studies by Atampugre (2022) and Naazie et al. (2023) in the Upper East and West regions of Ghana. The least implemented strategies among farmers were Agroforestry (2.99), soil conservation (2.83), and crop diversification (2.75). While these strategies are recognized for their long-term environmental benefits, farmers may perceive their impacts as gradual, requiring sustained investment and management before significant benefits are realized.

A critical finding is the mismatch between adoption rates and perceived effectiveness. Despite irrigation being the most highly rated strategy, it remains one of the least adopted measures due to the fact that

farmers recognize its effectiveness but face serious challenges in its implementation, largely due to its financial, infrastructure, and institutional constraints. The low adoption rate of highly effective strategies, according to the respondents, may be influenced by limited access to resources rather than lack of awareness of their benefits.

Table 6  
Effectiveness of adaptation strategies among respondents

| Adaptation Strategy        | Mean Effectiveness | SD   |
|----------------------------|--------------------|------|
| Irrigation                 | 3.92               | 0.83 |
| Livelihood diversification | 3.68               | 1.16 |
| Agroforestry               | 2.99               | 1.00 |
| Soil conservation          | 2.83               | 1.09 |
| Crop diversification       | 2.75               | 0.89 |
| Migration                  | 2.44               | 1.27 |

### 3.9 Constraints to climate change adaptation in ORB

The mean constraint scores among respondents were identified and ranked (Table 7). The results identified economic and financial constraints as the most significant barrier. This observation may be attributed to the widespread financial limitations that characterized smallholder farmers in the region, restricting farmers from investing in effective adaptation measures. These findings are aligned with those of Antwi-Agyei et al. (2025) and Birago et al. (2020) in southern Ghana, who identified financial and economic issues as the key constraints to climate adaptation.

Table 7  
Constraint scores by barrier domain

| Constraint Domain                                                                                                                     | Mean | SD   | Rank |
|---------------------------------------------------------------------------------------------------------------------------------------|------|------|------|
| Economic/Financial                                                                                                                    | 3.82 | 0.88 | 1    |
| Information/Knowledge                                                                                                                 | 3.50 | 1.12 | 2    |
| Institutional                                                                                                                         | 3.44 | 1.06 | 2    |
| Policy/Governance                                                                                                                     | 3.44 | 0.94 | 2    |
| Infrastructure                                                                                                                        | 3.37 | 1.00 | 5    |
| Environmental/Natural                                                                                                                 | 3.32 | 0.99 | 6    |
| Technological                                                                                                                         | 3.30 | 1.10 | 7    |
| Social/Cultural                                                                                                                       | 3.05 | 1.25 | 8    |
| Overall constraint index                                                                                                              | 3.41 | 0.58 | -    |
| <b>Note: Scale: 1 = Not a constraint, 2 = Slight, 3 = Constraint, 4 = Moderate, 5 = Severe. Cronbach <math>\alpha</math> = 0.683.</b> |      |      |      |

Information and knowledge gaps were the second most significant factor influencing CC adaptation strategies, along with institutional barriers. This finding suggests persistent gaps in climate information dissemination, extension service delivery, and institutional support mechanisms available to smallholder farmers. The limited access to timely and relevant climate information may hinder farmers' ability to make informed decisions, while weak institutional support reduces the effectiveness of adaptation interventions. These findings are consistent with those of Boakye et al.(2023) and Alidu et al.(2022), who identified inadequate climate information services and weak institutional support as major challenges to climate change adaptation among farmers in Ghana.

Policy and governance challenges were also prominent, largely reflecting challenges in the land tenure system and weak enforcement of regulatory frameworks. Infrastructure-related barriers, including poor road networks and inadequate irrigation facilities, further constrained adaptation strategies by farmers. These results corroborated those of Mwinkom et al.(2021), who also reported similar findings in Ghana. In contrast, the lower ranking suggests that traditional norms, cultural practices, and social relations do affect how farmers perceive and respond to climate change, as compared to more pressing structural constraints. Even though cultural beliefs or gender roles may shape decision-making within households or communities, their impact does not significantly affect farmers' adaptation strategies. In addition, the lower severity rate of social and cultural constraints may reflect the presence of social networks, community cooperation, and shared learning systems that help farmers exchange information and support adaptation.

However, gender disparities, unequal access to household resources, and culturally embedded decision-making structures may affect adaptation practices and implementation. This result implies that, while social and cultural factors are present, they are overshadowed by dominant economic, institutional, infrastructural, and technological constraints that directly limit farmers' capacity to respond effectively to the impacts of climate change in the basin.

The composite constraint index score of 3.41 suggests that farmers in the basin experience moderate to high levels of constraints. Suggesting that adaptation strategies are not hindered by a single dominant barrier, but by multiple interacting factors such as economic, institutional, infrastructural, environmental, technological, and socio-cultural issues. The results also suggest that while some coping mechanisms may exist at the individual or community level, they are not sufficient to address the impact. The presence of multiple constraints points to a systemic adaptation challenge, where weaknesses in one breadth may compound deficiencies in other areas. This index reflects a context of constrained adaptive capacity, where farmers operate under persistent pressures that limit the effectiveness and sustainability of climate change adaptation strategies in the basin.

### **3.10 Constraint by gender and institutional access**

In assessing whether aggregate constraint patterns can conceal important domain-specific differences. Constraint domains were disaggregated by gender (Fig. 4A) and extension-service access (Fig. 4B).

The results (Fig. 4A) reveal that the aggregate constraint index did not show any significant differences between males and females; however, female farmers reported higher economic and financial constraints (mean = 4.00) compared to male farmers (3.76), as well as higher social and cultural constraints (mean = 3.22) compared to male farmers (2.99). In contrast, male farmers reported higher policy and governance constraints of 3.59 compared to female farmers of 2.99. These suggest that women adaptation challenges are primarily related to resource access and socio-cultural domains, while men are more with governance, policy, and land-management issues. These results align with the findings of Bessah et al. (2021) and Eric et al. (2025), who highlighted the challenges women faced in accessing resources, credit facilities, and decision-making opportunities, while men are directly involved with governance structures and land administration processes.

The results (Fig. 4B) assessed the distribution of constraint domains between farmers with and without access to extension services. The results indicated that farmers with extension access report higher mean constraint scores across all domains, except for institutional constraints, where farmers without extension access reported slightly higher scores. Additionally, large disparities were observed for social and cultural constraints, with farmers reporting a mean score of 3.74 compared with 2.37 without access. Similarly, technology was rated significantly higher by farmers with extension access of 3.62 than those without access 2.97. This trend suggests that farmers' access to extension services may enhance farmers' awareness of the social, behavioural, and technological barriers that hinder effective adaptation. Thus, farmers with access to extension services are able to recognize, evaluate, and articulate adaptation constraints more than those with limited or no access. Adaptation, suggesting the

critical role extension support plays in shaping adaptation behaviour of farmers (Alidu et al., 2022; Awuni et al., 2023)

### **3.12 Inter-domain correlation of adaptation constraints**

In assessing the association between adaptation constraints, the Pearson correlation matrix was used (Fig. 6). The results reveal positive correlation coefficient values ( $r = 0.23$  to  $r = 0.41$ ), which indicate that farmers experiencing high constraints in one domain are likely to experience the same in other domains. The weak to moderate correlations could suggest that the domains reflect distinct dimensions of adaptation constraints rather than a single underlying factor. This result is consistent with the findings of Abdullai et al. (2023) in the Northern region of Ghana and Disse et al. (2018) in the Blue Nile basin. The results also established a strong relationship between policy/governance and institutional constraints of  $r = 0.41$ , institutional and infrastructure  $r = 0.40$ , economic and institutional of  $r = 0.39$ , and technological and infrastructure of  $r = 0.39$ . These findings highlight the interconnected nature of governance, institutions, infrastructure, and economic resources in shaping farmers' adaptive strategies.

The moderate positive correlations observed for institutional and information constraints, institutional and technological constraints, infrastructure and policy constraints, and information and technological constraints suggest that limited access to institutional support simultaneously affects farmers' access to climate information, extension services, and adaptation technologies. Similarly, deficiencies in infrastructure may reinforce governance-related barriers, creating a cycle that constrains adaptation efforts. In contrast, social/cultural constraints exhibit the weakest correlations with the other domains ( $r = 0.23$  to  $r = 0.31$ ). The lowest correlation occurs between social/cultural and policy/governance constraints ( $r = 0.23$ ), and between social/cultural and environmental constraints ( $r = 0.24$ ). This therefore suggests that social and cultural barriers operate independently of the other constraints, such as institutional, environmental, and policy-related factors. Norms, beliefs, traditions, and community practices may therefore constitute a distinct dimension of adaptation constraints that cannot be addressed solely through improvements in governance, infrastructure, or information provision.

### **3.13 Adaptation constraints and socioeconomic characteristics**

The relationship between adaptation constraints and socioeconomic characteristics (Table 8) was determined using Spearman rank-order correlation model. This examines the relationship between the composite adaptation constraint index and socioeconomic variables. The results revealed that farm size was the only variable significantly associated with constraint severity ( $r = -0.139$ ,  $p = 0.016$ ). The negative correlation suggests that farmers with larger landholdings tend to experience slightly lower levels of adaptation constraints. Although the relationship is weak, it suggests that larger farms may provide greater opportunities for resource mobilisation, income generation, and investment in adaptation measures. Additionally, large landholdings may also enable farmers to diversify production systems and spread climate-related risks more effectively than farmers operating on small land. These results agree with Khanal (2020) and Bera et al. (2021), who reported similar findings in India and Nepal.

Table 8  
Composite constraint index and socioeconomic  
variables

| Variable             | Spearman's (r) | p-value |
|----------------------|----------------|---------|
| Age                  | -0.030         | 0.604   |
| Farming experience   | -0.075         | 0.194   |
| Farm size            | -0.139         | 0.016   |
| Household size       | 0.009          | 0.878   |
| Education level      | -0.058         | 0.320   |
| Climate impact index | -0.077         | 0.185   |

In contrast, age showed no significant relationship with the constraint index ( $r = -0.030$ ,  $p = 0.604$ ), demonstrating that older farmers do not necessarily perceive fewer or greater adaptation barriers than younger farmers. This finding suggests that the experience and knowledge accumulated with age may be offset by other factors such as limited access to resources, institutional support, or changing climatic conditions. Similarly, farming experience was not significantly correlated with adaptation constraints ( $r = -0.075$ ,  $p = 0.194$ ). While more experienced farmers may possess greater practical knowledge of local environmental conditions and adaptation practices, the absence of a significant relationship indicates that experience alone is insufficient to overcome structural barriers such as financial limitations, inadequate infrastructure, and institutional constraints. The relationship between household size and adaptation constraints was negligible and statistically insignificant ( $r = 0.009$ ,  $p = 0.878$ ). This implies that large households neither significantly reduce nor increase perceived adaptation barriers. However, large households may provide additional labour for agricultural activities, but may also place greater demands on household resources, resulting in no clear net effect on adaptation capacity.

Furthermore, educational level exhibited a weak negative but non-significant relationship with the constraint index ( $r = -0.058$ ,  $p = 0.320$ ). Indicating that higher levels of formal education do not necessarily translate into lower perceived adaptation constraints. However, education may enhance access to information and improve decision-making capabilities; broader structural challenges such as limited access to credit, technology, and institutional support may continue to constrain adaptation regardless of educational status. The climate impact index was also not significantly associated with adaptation constraint ( $r = -0.077$ ,  $p = 0.185$ ). This suggests that farmers who experienced greater climate related impacts do not necessarily perceive higher adaptation barriers. This may be because exposure to climate impacts may stimulate learning and adaptation responses and reduce the perceived severity of certain constraints. Also, adaptation barriers are shaped more strongly by socioeconomic and institutional conditions than by the direct magnitude of climate impacts experienced.

### 3.14 Determinants of constraint severity

Results from OLS regression of the composite constraint index (Table 9) reveal that the model accounts for 77.2% of the variation in the level of constraint ( $R^2=0.772$ , adjusted  $R^2=0.763$ ,  $F(11,288) = 224.71$ ,  $p < 0.001$ ). The Variance Inflation Factor (VIF) values for all variables were less than the maximum of 10, which indicates an acceptable level of multicollinearity (Frimpong et al., 2023). The strongest negative predictor ( $\beta=-1.177$ ,  $SE = 0.084$ ,  $t=-14.03$ ,  $p < 0.001$ ) was training received, suggesting that farmers who had training on climate/drought management perceived lower constraints. Education level ( $\beta=-0.310$ ,  $SE = 0.010$ ,  $t=-29.63$ ,  $p < 0.001$ ) and farming experience ( $\beta=-0.048$ ,  $SE = 0.003$ ,  $t=-16.43$ ,  $p < 0.001$ ) had significant negative effects on constraint perception. Extension access ( $\beta = 0.981$ ,  $SE = 0.049$ ,  $t = 19.93$ ,  $p < 0.001$ ), credit access ( $\beta = 0.781$ ,  $SE = 0.094$ ,  $t = 8.27$ ,  $p < 0.001$ ), and climate information access ( $\beta = 0.453$ ,  $SE = 0.048$ ,  $t = 9.53$ ,  $p < 0.001$ ) were all positively associated with constraint severity.

Despite this, the results concluded that higher institutional engagement may lead to greater awareness of the barriers, but does not necessarily eliminate them. Also, the climate impact index was a positive predictor of constraint severity, indicating that the higher the climate exposure, the greater the perception of a climate constraint, with age and gender not significant in the overall model.

Table 9  
Determinants of composite constraint index

| Predictor Variable                                                                                                                                                                              | $\beta$                       | SE                                | t-value                        | p-value                          | VIF                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-----------------------------------|--------------------------------|----------------------------------|---------------------|
| Intercept                                                                                                                                                                                       | 3.575                         | 0.110                             | 32.60                          | < 0.001***                       | -                   |
| Age                                                                                                                                                                                             | -0.004                        | 0.003                             | -1.34                          | 0.180                            | 3.94                |
| Farm Experience                                                                                                                                                                                 | -0.048                        | 0.003                             | -16.43                         | < 0.001***                       | 4.43                |
| Farm Size                                                                                                                                                                                       | 0.012                         | 0.004                             | 3.21                           | 0.001**                          | 5.71                |
| Household Size                                                                                                                                                                                  | 0.046                         | 0.009                             | 5.23                           | < 0.001***                       | 4.39                |
| Education Level                                                                                                                                                                                 | -0.310                        | 0.010                             | -29.63                         | < 0.001***                       | 2.54                |
| Gender (Male = 1)                                                                                                                                                                               | -0.022                        | 0.037                             | -0.61                          | 0.543                            | 2.39                |
| Extension Access                                                                                                                                                                                | 0.981                         | 0.049                             | 19.93                          | < 0.001***                       | 5.77                |
| Credit Access                                                                                                                                                                                   | 0.781                         | 0.094                             | 8.27                           | < 0.001***                       | 7.72                |
| Climate Info Access                                                                                                                                                                             | 0.453                         | 0.048                             | 9.53                           | < 0.001***                       | 3.29                |
| Training Received                                                                                                                                                                               | -1.177                        | 0.084                             | -14.03                         | < 0.001***                       | 6.39                |
| Climate Impact Index                                                                                                                                                                            | 0.346                         | 0.033                             | 10.53                          | < 0.001***                       | 3.15                |
| <b>Model Statistics</b>                                                                                                                                                                         | <b><math>R^2=0.772</math></b> | <b>Adj-<math>R^2=0.763</math></b> | <b><math>F = 224.71</math></b> | <b><math>p &lt; 0.001</math></b> | <b>AIC = 107.94</b> |
| <b>Note: ***<math>p &lt; 0.001</math>, **<math>p &lt; 0.01</math>, *<math>p &lt; 0.05</math>. VIF =Variance Inflation Factor, HC3 robust standard errors. AIC =Akaike Information Criterion</b> |                               |                                   |                                |                                  |                     |

### 3.15 Determinants of adaptation breadth

The negative binomial regression results (Table 10) reveal that gender was a significant predictor, with male farmers exhibiting 63.2% higher rates of adaptation strategies compared to females (IRR = 1.632,  $p < 0.001$ ), reflecting persistent gender disparities in access to productive resources, information, and decision-making autonomy in the study area. Access to extension services emerged as a strong positive predictor of adaptation breadth (IRR = 1.843,  $p < 0.001$ ), indicating that farmers with extension support were 84.3% more likely to adopt a wider range of adaptation strategies than those without access. Additionally, farm size also has a positive and significant effect (IRR = 1.028,  $p = 0.001$ ), suggesting that each additional acre increased the rate of strategy adoption by 2.8%. This may be attributed to large landholders having greater flexibility and capacity to experiment with multiple adaptation options. Age showed a modest but significant positive effect (IRR = 1.014,  $p = 0.001$ ), indicating that older farmers tend to adopt a broader range of adaptation strategies, largely due to accumulated farming experience and stronger social networks reported earlier by Khanal et al. (2020).

| Table 10<br>Determinants of adaptation strategy                                                                                                                                                                                        |               |                 |            |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------------|------------|
| Predictor Variable                                                                                                                                                                                                                     | IRR           | 95% CI          | p-value    |
| Age                                                                                                                                                                                                                                    | 1.014         | 1.006–1.023     | 0.001**    |
| Education Level                                                                                                                                                                                                                        | 0.896         | 0.805–0.998     | 0.046*     |
| Gender (Male = 1)                                                                                                                                                                                                                      | 1.632         | 1.275–2.089     | < 0.001*** |
| Extension Access                                                                                                                                                                                                                       | 1.843         | 1.304–2.606     | < 0.001*** |
| Credit Access                                                                                                                                                                                                                          | 1.285         | 0.954–1.731     | 0.099      |
| Farm Size                                                                                                                                                                                                                              | 1.028         | 1.011–1.046     | 0.001**    |
| Household Size                                                                                                                                                                                                                         | 0.965         | 0.931–1.001     | 0.053      |
| Climate Impact Index                                                                                                                                                                                                                   | 1.111         | 0.946–1.304     | 0.201      |
| Model Statistics                                                                                                                                                                                                                       | Log-L=-428.45 | LLR $p < 0.001$ |            |
| <b>Note:</b> IRR=Incidence Rate Ratio. *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ . Dependent variable: Log-likelihood = - 428.45; Likelihood ratio = LLR $p < 0.001$ . IRR = IRR *** $p < 0.001$ , ** $p < 0.01$ , * $p < 0.05$ . |               |                 |            |

In contrast, education level exhibited a statistically significant negative relationship with adaptation breadth (IRR = 0.896,  $p = 0.046$ ). This may be attributed to the fact that more educated individuals, particularly those engaged in non-farm employment such as civil service, may diversify away from agricultural investments and adopt fewer on-farm adaptation strategies (Naazie et al., 2023; Omerkhil et al., 2020). Although the climate impact index approached a significant level (IRR = 1.11,  $p = 0.20$ ), it was not a statistically significant predictor. This indicates that the severity of climate impacts alone does not necessarily translate into a greater diversification of adaptation strategies, highlighting the importance of institutional and resource-based factors in shaping adaptive behaviour.

### 3.17 Limitations and uncertainty

The assessment of climate change impacts, adaptation strategies, and adaptation constraints relied largely on farmers' perceptions and experiences, which could be influenced by recall bias and subjective responses. Even though household surveys were triangulated with KIIs and FGDs, some degree of bias may still exist. Also, the study focused on selected riparian communities within the ORB, which may not fully represent all agroecological, socioeconomic, and institutional conditions across the entire basin or other regions of Ghana, leading to overgeneralization of the causes and effects of climate change, which often elude other interacting factors.

The analysis of climate data only considered rainfall and temperature and did not incorporate other climatic variables, such as soil moisture or evapotranspiration, which may also influence agricultural adaptation. The cross-sectional nature of the study provides a snapshot of farmers' adaptation practices and perceived constraints at a single point in time and therefore cannot capture temporal changes in adaptation behaviour or establish causal relationships. Future studies should consider longitudinal approaches that integrate socioeconomic, biophysical, and policy datasets to better understand the long-term dynamics of adaptation strategies among smallholder farmers in the ORB.

## **4. Conclusion and Recommendations**

### **4.1 Conclusion**

The study revealed significant interannual variability in rainfall and temperature in the basin, with rainfall patterns showing a slight increasing trend, and temperature showing a gradual warming trend, even though neither trend was statistically significant. The observed climatic variability, coupled with increasing temperatures, suggesting growing climatic uncertainty with risks to agricultural productivity, water resources, and ecosystem sustainability. Food insecurity, water scarcity, drought stress, and reduced crop yield were the most severe impacts experienced by households. The most practiced adaptation strategies in the basin were crop diversification, changes in planting dates, soil conservation practices, livelihood diversification, agroforestry, irrigation, and migration. Irrigation was perceived as the most effective adaptation measure among farmers, yet it remained one of the least practiced strategies due to substantial financial, infrastructural, and institutional demand in its implementation.

The study also established that adaptation constraints are multidimensional and interconnected, with financial barriers being the most significant constraint, with information and knowledge gaps, institutional limitations, and policy. The constraint index indicated moderate-to-high adaptation barriers, which suggests that farmers operate within a context characterised by multiple reinforcing limitations. The study further highlighted that male and female farmer experienced similar levels of adaptation constraints, but the rate of adoption by male farmers was significantly higher than that of female farmers. Adaptation strategies in the ORB are constrained not by lack of awareness or willingness to adapt, but more by inadequate access to financial resources, climate information, extension support, technology, and institutional services. Addressing these barriers is critical to enhancing climate

resilience, protecting rural livelihoods, and advancing sustainable agricultural development across the basin.

## 4.2 Recommendations

To address the multiple barriers affecting climate change adaptation in the ORB, coordinated and targeted interventions are needed to strengthen adaptation capacity and enhance resilience to climate variability. It is recommended that;

1. Government agencies, financial institutions, and development partners should establish climate credit schemes with flexible collateral terms tailored to the needs of smallholder farmers in the basin. This will enable farmers to invest in irrigation facilities, improved seeds, soil conservation measures, and other adaptation technologies.
2. Ghana Meteorological Agency, NADMO, MOFA, and District Assemblies should strengthen community-based climate information services and early warning systems. Weather forecasts, drought advisories, and flood alerts should be disseminated through local radio stations, mobile phone platforms, and community information centres.
3. Research should explore household adaptation trajectories over time using longitudinal data to investigate the interactions among climate change, land-use change, hydrological variability, and adaptation outcomes.

## Declarations

### **Ethics approval and consent to participate:**

The study was approved by the Humanities and Social Science Research Ethics Committee (HUSSREC) of Kwame Nkrumah University of Science and Technology in line with the ethical regulations and guidelines of the committee and in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants before data collection

### **Consent for publication:**

Not applicable.

### **Competing interests:**

Author(s) declared no potential conflict of interest

### **Clinical trial number**

Not applicable.

## Funding

This study received no funding from any public or commercial entity

## Author Contribution

CRedit: Z. O: Conceptualization, Methodology, Investigation, Data curation, Writing, Formal analysis, Visualization; M. C: Methodology, Review & Editing, Supervision; K. N: Writing and Editing, Supervision; B. E: Writing and Editing, Visualization; O.S.A: Methodology, Validation, Writing and Editing. B. N. B: Writing, Reviewing, and Editing. N. E: Software, Validation, Formal Analysis.

## Data Availability

Data will be provided upon request from the corresponding author

## References

1. - A-MA, M. S., - SNA. Smallholder Farmer Adaptation Strategies to Climate Change in Northern Ghana: Evidence from Gushegu Municipality. *Int J Multidisciplinary Res.* 2023;5(2):1–16. <https://doi.org/10.36948/ijfmr.2023.v05i02.2117>.
2. Abungba JA, Adjei KA, Gyamfi C, Odai SN, Pingale SM, Khare D. Implications of Land Use/Land Cover Changes and Climate Change on Black Volta Basin Future Water Resources in Ghana. *Sustain (Switzerland).* 2022;14(19). <https://doi.org/10.3390/su141912383>.
3. ALHASSAN H. Farmers' Choice of Adaptation Strategies To Climate Change and Variability in the Arid Region of Ghana. *Rev Agricultural Appl Econ.* 2019;22(1):32–40. <https://doi.org/10.15414/raae.2019.22.01.32-40>.
4. Alhassan I, Antwi-Agyei P, Adzawla W, Sima M. Factors influencing the access and utilization of climate information by farmers from different climate-vulnerable districts of the Northern Region, Ghana. *Clim Serv.* 2025;38(March):100557. <https://doi.org/10.1016/j.cliser.2025.100557>.
5. Alhassan SI, Kuwornu JKM, Osei-Asare YB. Gender dimension of vulnerability to climate change and variability: Empirical evidence of smallholder farming households in Ghana. *Int J Clim Change Strateg Manag.* 2019;11(2):195–214. <https://doi.org/10.1108/IJCCSM-10-2016-0156>.
6. Alidu AF, Man N, Ramli NN, Haris M, N. B., Alhassan A. Smallholder farmers' access to climate information and climate-smart adaptation practices in the northern region of Ghana. *Heliyon.* 2022;8(5). <https://doi.org/10.1016/j.heliyon.2022.e09513>.
7. Ampadu HK. (2017). University of Cape Coast. November 9–10.
8. Ampim PAY, Ogbe M, Obeng E, Akley EK, Maccarthy DS. Land cover changes in Ghana over the past 24 years. *Sustain (Switzerland).* 2021;13(9). <https://doi.org/10.3390/su13094951>.
9. Ampofo S, Boadi Manu MA, Ampadu B, Adonadaga M-G. Impact of Landuse and Land Cover Changes on Hydrological Components of the Oti Sub-Basin of Ghana. *Ghana J Sci Technol Dev.*

- 2022;8(2):60–70. <https://doi.org/10.47881/375.967x>.
10. Antwi-Agyei P, Baffour-Ata F, Alhassan J, Kpenekuu F, Dougill AJ. (2025). Understanding the barriers and knowledge gaps to climate-smart agriculture and climate information services: A multi-stakeholder analysis of smallholder farmers' uptake in Ghana. *World Development Sustainability*, 6(July 2024). <https://doi.org/10.1016/j.wds.2025.100206>
  11. Arfasa GF, Owusu-Sekyere E, Doke DA. (2024). Climate Change Projections and Impacts on Future Temperature, Precipitation, and Streamflow in the Veia Catchment, Ghana. *Environmental Challenges*, 14(December 2023), 100813. <https://doi.org/10.1016/j.envc.2023.100813>
  12. Arhin A. (2022). *Climate Change Adaptation in Ghana: Strategies, Initiatives, and Practices*. September, 1–15.
  13. Awotwi A, Yeboah F, Kumi M. Assessing the impact of land cover changes on water balance components of White Volta Basin in West Africa. *Water Environ J*. 2015;29(2):259–67. <https://doi.org/10.1111/wej.12100>.
  14. Awuni S, Adarkwah F, Ofori BD, Purwestri RC, Bernal H, D. C., Hajek M. Managing the challenges of climate change mitigation and adaptation strategies in Ghana. *Heliyon*. 2023;9(5):e15491. <https://doi.org/10.1016/j.heliyon.2023.e15491>.
  15. Azhoni A, Goyal MK. Diagnosing climate change impacts and identifying adaptation strategies by involving key stakeholder organisations and farmers in Sikkim, India: Challenges and opportunities. *Sci Total Environ*. 2018;626:468–77. <https://doi.org/10.1016/j.scitotenv.2018.01.112>.
  16. Azumah SB, Adzawla W, Donkoh SA, Anani PY. Effects of climate adaptation on households' livelihood vulnerability in South Tongu and Zabzugu districts of Ghana. *Climate Dev*. 2021;13(3):256–67. <https://doi.org/10.1080/17565529.2020.1757398>.
  17. Beckline M, Mukete N, Mukete T. (2025). *Impact of extreme weather events on agricultural production and household livelihoods in rural Malawi*. 1–12.
  18. Benebere P, Asante F, Odame Appiah D. Hindrances to adaptation to water insecurity under climate variability in peri-urban Ghana. *Cogent Social Sci*. 2017;3(1). <https://doi.org/10.1080/23311886.2017.1394786>.
  19. Bera A, Taloor AK, Meraj G, Kanga S, Singh SK, Đurin B, Anand S. (2021). Climate vulnerability and economic determinants: Linkages and risk reduction in Sagar Island, India; A geospatial approach. *Quaternary Science Advances*, 4. <https://doi.org/10.1016/j.qsa.2021.100038>
  20. Bessah E, Raji AGO, Taiwo OJ, Agodzo SK, Ololade OO, Strapasson A, Donkor E. Gender-based variations in the perception of climate change impact, vulnerability and adaptation strategies in the Pra River Basin of Ghana. *Int J Clim Change Strateg Manag*. 2021;13(4–5):435–62. <https://doi.org/10.1108/IJCCSM-02-2020-0018>.
  21. Birago A, Gyimah K, Bagbohouna M. (2020). *Climate Change Adaptation among Smallholder Farmers: Evidence from Ghana*. 614–638. <https://doi.org/10.4236/acs.2020.104032>
  22. Bismark M-B, Mexoese N, Pearl N, Kojo Samuel Y, A., Kwabena Paul O. Interplay of Climate Variability, Land Use Change, Crop Yield and Farm Households' Food Security in Offin River Basin,

- Ghana. *Int J Sustainable Dev Res*. 2021;7(4):102. <https://doi.org/10.11648/j.ijdsr.20210704.14>.
23. Biswas S, Chatterjee S, Roy DC. Understanding of farmers' perception of climate change and adaptation strategies: A case study in Jhargram district of West Bengal, India. *J Appl Nat Sci*. 2020;12(2):207–12. <https://doi.org/10.31018/jans.v12i2.2241>.
  24. Bitasse EO, Moutoré Y, Dansoip G. Stakeholders' perceptions and strategies to climate change resilience in Kara and Dapaong, Togo. *Natural Resources, Socio-Ecological Sensitivity and Climate Change in the Volta-Oti Basin, West Africa*. Issue February; 2020. <https://doi.org/10.1201/9781003106708-7>.
  25. Boakye GO, Wiafe JO, Frimpong F. Barriers to Climate Change Communications. *Ghana J Geogr*. 2023;15(3):1–25. <https://doi.org/10.4314/gjg.v15i3.1>.
  26. Dembélé M, Vrac M, Ceperley N, Zwart SJ, Larsen J, Dadson SJ, Mariéthoz G, Schaefli B. Contrasting changes in hydrological processes of the Volta River basin under global warming. *Hydrol Earth Syst Sci*. 2022;26(5):1481–506. <https://doi.org/10.5194/hess-26-1481-2022>.
  27. Disse M, Mekonnen F, Duan Z, Rientjes T. Analysis of the combined and single effects of LULC and climate change on the streamflow of the Upper Blue Nile River Basin (UBNRB): Using statistical trend tests, remote sensing land cover maps and the SWAT model. *Geophys Res Abstracts*. 2018;20:2018–18688.
  28. Eric K, Enock A, Isaac A, Bismark M. (2025). *Social Sciences & Humanities Open. Land degradation, environmental justice, and socio-cultural dynamics in the Fanteakwa North District of Ghana*. 12(September).
  29. Fagariba CJ, Song S, Baoro SKGS. Climate change adaptation strategies and constraints in Northern Ghana: Evidence of farmers in Sissala West District. *Sustain (Switzerland)*. 2018;10(5):1–18. <https://doi.org/10.3390/su10051484>.
  30. Frimpong BF, Koranteng A, Opoku FS. Analysis of urban expansion and its impact on temperature utilising remote sensing and GIS techniques in the Accra Metropolis in Ghana (1986–2022). *SN Appl Sci*. 2023;5(8). <https://doi.org/10.1007/s42452-023-05439-z>.
  31. Gashaw T, Tulu T, Argaw M, Worqlul AW. Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. *Sci Total Environ*. 2018;619–620:1394–408. <https://doi.org/10.1016/j.scitotenv.2017.11.191>.
  32. Gedefaw M, Girma A, Denghua Y, Hao W, Agitew G. Farmer's Perceptions and Adaptation Strategies to Climate Change, Its Determinants and Impacts in Ethiopia: Evidence from Qwara District. *Earth Sci Clim Change*. 2018;9(7). <https://doi.org/10.4172/2157-7617.1000481>.
  33. Girma A, Yan D, Wang K, Birara H, Gedefaw M, Batsuren D, Abiyu A, Qin T, Mekonen T, Abate A. (2023). *Climate Change, Land Use, and Vegetation Evolution in the Upper Huai River Basin*. <https://doi.org/10.3390/atmos14030512>
  34. Gyimah ABK, Antwi-Agyei P, Adom-Asamoah G, Baffour-Ata F. Drivers of adaptive capacity of rural women farmers: The role of climate action and information mediums in rural Ghana. *Clim Resil Sustain*. 2024;3(2):1–19. <https://doi.org/10.1002/cli2.67>.

35. Gyimah ABK, Bagbohouna M, Sanogo NditM, Gibba A. Climate Change Adaptation among Smallholder Farmers: Evidence from Ghana. *Atmospheric Clim Sci*. 2020;10(04):614–38. <https://doi.org/10.4236/acs.2020.104032>.
36. Hyandye CB, Worqul A, Martz LW, Muzuka ANN. The impact of future climate and land use/cover change on water resources in the Ndembera watershed and their mitigation and adaptation strategies. *Environ Syst Res*. 2018;7(1). <https://doi.org/10.1186/s40068-018-0110-4>.
37. Issaka, Donkoh SA, Kranjac-Berisavljevic. Factors Influencing Resilience to Climate Variability Among Smallholder Lowland Rice Farming Households In Northern Ghana. *Int J Dev*. 2023;10(1):1–13. <https://doi.org/10.47740/772.UDSIJD6i>.
38. Kabobah L, Nukpezah D, Ntiama-Baidu Y. Adaptive capacity of farmers to climate change in the Kassena Nankana municipality of Ghana: Implications for climate adaptation strategies. *West Afr J Appl Ecol*. 2018;26:14–26.
39. Kangah H, Atampugre G. Farmer adoption of planned climate adaptation: Institutional constraints and opportunities in the Upper East Region of Ghana Farmer adoption of planned climate adaptation : Institutional constraints and opportunities in the Upper East Region of Ghana. *Cogent Social Sci*. 2022;8(1). <https://doi.org/10.1080/23311886.2022.2035048>.
40. Kassaye SM, Tadesse T, Tegegne G, Hordofa AT. Quantifying the climate change impacts on the magnitude and timing of hydrological extremes in the Baro River Basin, Ethiopia. *Environ Syst Res*. 2024;13(1):1–15. <https://doi.org/10.1186/s40068-023-00328-1>.
41. Khanal G. Climate Change Adaptation Undertaken by Small-scale Farmers in Nepal: A Reference from Tinau River Basin. *Quest J Manage Social Sci*. 2020;2(1):93–105. <https://doi.org/10.3126/qjmss.v2i1.29025>.
42. Kimbi SB, Onodera S, Wang K, Kaihotsu I, Shimizu Y. Assessing the Impact of Urbanization and Climate Change on Hydrological Processes in a Suburban Catchment. *Environments*. 2024;11(10):225. <https://doi.org/10.3390/environments11100225>.
43. Koffi B, Brou AL, Kouadio KJO, Ebodé VB, N'guessan KJY, Yangouliba GI, Yaya K, Brou D, Kouassi KL. (2023). Impact of climate and land use/land cover change on Lobo reservoir inflow, West-Central of Côte d'Ivoire. *Journal of Hydrology: Regional Studies*, 47(December 2022). <https://doi.org/10.1016/j.ejrh.2023.101417>
44. Kolekar SS, Mishra A, Choudhari P, Choudhari NR. Identification of specific areas for water conservation measures using Geoinformatics approach. *Arab J Geosci*. 2021;14(6). <https://doi.org/10.1007/s12517-021-06721-3>.
45. Malede DA, Alamirew T, Andualem TG. Integrated and Individual Impacts of Land Use Land Cover and Climate Changes on Hydrological Flows over Birr River Watershed, Abbay Basin, Ethiopia. *Water (Switzerland)*. 2023;15(1). <https://doi.org/10.3390/w15010166>.
46. Mwanga E, Shaibu AG, Issaka Z. Construction of the water balance model for the Bontanga irrigation dam in Northern Ghana. *J Water Clim Change*. 2024;15(7):2918–39. <https://doi.org/10.2166/wcc.2024.449>.

47. Mwinkom FXK, Damnyag L, Abugre S, Alhassan SI. Factors influencing climate change adaptation strategies in North-Western Ghana: evidence of farmers in the Black Volta Basin in Upper West Region. *SN Appl Sci.* 2021a;3(5). <https://doi.org/10.1007/s42452-021-04503-w>.
48. Mwinkom FXK, Damnyag L, Abugre S, Alhassan SI. Factors influencing climate change adaptation strategies in North-Western Ghana: evidence of farmers in the Black Volta Basin in the Upper West Region. *SN Appl Sci.* 2021b;3(5):1–20. <https://doi.org/10.1007/s42452-021-04503-w>.
49. Naazie GK, Dakyaga F, Derbile EK. Agro-ecological intensification for climate change adaptation: tales on soil and water management practices of smallholder farmers in rural Ghana. *Discover Sustain.* 2023;4(1). <https://doi.org/10.1007/s43621-023-00142-w>.
50. Omerkhil N, Chand T, Valente D, Alatalo JM, Pandey R. (2020). Climate change vulnerability and adaptation strategies for smallholder farmers in Yangi Qala District, Takhar, Afghanistan. *Ecological Indicators*, 110(October 2019), 105863. <https://doi.org/10.1016/j.ecolind.2019.105863>
51. Osman Z, Zakari O, Gyamfi C, Ofosu SA. & ... Effects of Land Cover Changes on Ecosystem Services in the Kulpawn Catchment of the White Volta River Basin of Ghana. Available SSRN ..., 6(6), 100277. <https://doi.org/10.1016/j.regsus.2025.100277>
52. Pabi O, Egyir S, Attua EM. Flood hazard response to scenarios of rainfall dynamics and land use and land cover change in an urbanized river basin in Accra, Ghana. *City Environ Interact.* 2021;12:100075. <https://doi.org/10.1016/j.cacint.2021.100075>.
53. Roth D, Khan MSA, Jahan I, Rahman R, Narain V, Singh AK, Priya M, Sen S, Shrestha A, Yakami S. Climates of urbanization: local experiences of water security, conflict and cooperation in peri-urban South-Asia. *Clim Policy.* 2019;19(sup1):S78–93. <https://doi.org/10.1080/14693062.2018.1530967>.
54. Sadiq MA, Kuwornu JKM, Al-Hassan RM, Alhassan SI. Assessing maize farmers' adaptation strategies to climate change and variability in Ghana. *Agric (Switzerland).* 2019;9(5):1–17. <https://doi.org/10.3390/agriculture9050090>.
55. Sorre AM, Kurgat A, Sorre RM, Benard. (2017). *Adaptive Capacity to Climate Change among Smallholder Farmers in Busia County, Kenya.* 10(11), 40–48. <https://doi.org/10.9790/2380-1011014048>
56. Suabir M, Wei Z, Amatus L, Michael G, Kumi A. (2021). *The Impact of Climate Change on Rainfall Patterns in Ghana: A Zoning Adaptation Strategy through Developing Agroforestry.* 04(01), 26–38.
57. Sun X, Gao Y, Xin T, Song N. (2021). *Binary Restrictive Threshold Method for Item Exposure Control in Cognitive Diagnostic Computerized Adaptive Testing.* 12(August), 1–9. <https://doi.org/10.3389/fpsyg.2021.517155>
58. Tan ML, Ibrahim AL, Yusop Z, Duan Z, Ling L. (2015). Impacts of land-use and climate variability on hydrological components in the Johor River basin, Malaysia. *Hydrological Sciences Journal, April* 2015, 1–17. <https://doi.org/10.1080/02626667.2014.967246>
59. Tengapoe K, Baddianaah I, Agyemang I. Anthropogenic-induced land use land cover dynamics of the Black Volta River Corridor in north-western Ghana, 2011–2021. *Trees Forests People.* 2023;14(September):100449. <https://doi.org/10.1016/j.tfp.2023.100449>.

60. Wang Y, He N. (2026). *Dynamic Threshold Determination Method for Triggering Critical Rainfall in Mountainous Debris Flow*. 1–17.

61. Yahaya M, Mensah C, Addaney M, Damoah-Afari P, Kumi N. (2023). *Climate change and adaptation strategies in rural Ghana: a study on smallholder farmers in the Mamprugu-Moaduri district*. January 2026. <https://doi.org/10.1108/IJCCSM-08-2022-0110>

62. Zothanzama J, Lalzazovi ST, Lalmalsawma S. Village-level inherent vulnerability of Champhai district to climate change. *Water Resour Approach*. 2025;40(1):664–77.

Figures

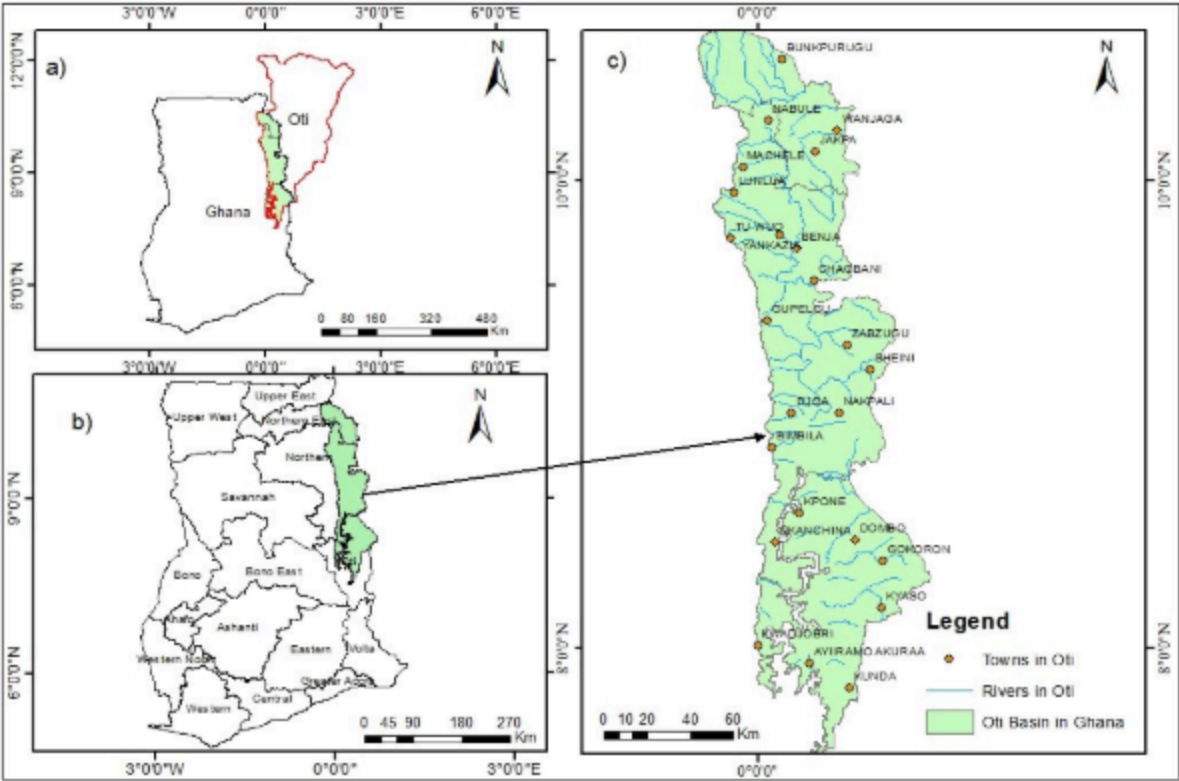


Figure 1

Map of the study area

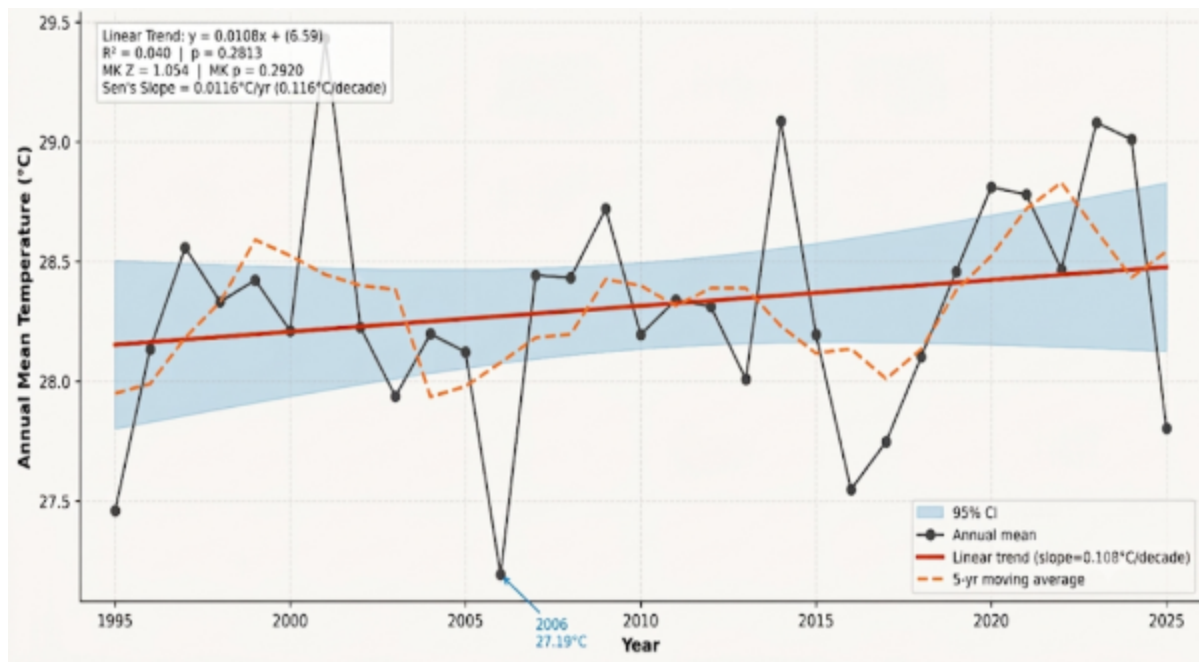


**Figure 2**

Trend in annual mean temperature in the ORB from 1995 to 2025

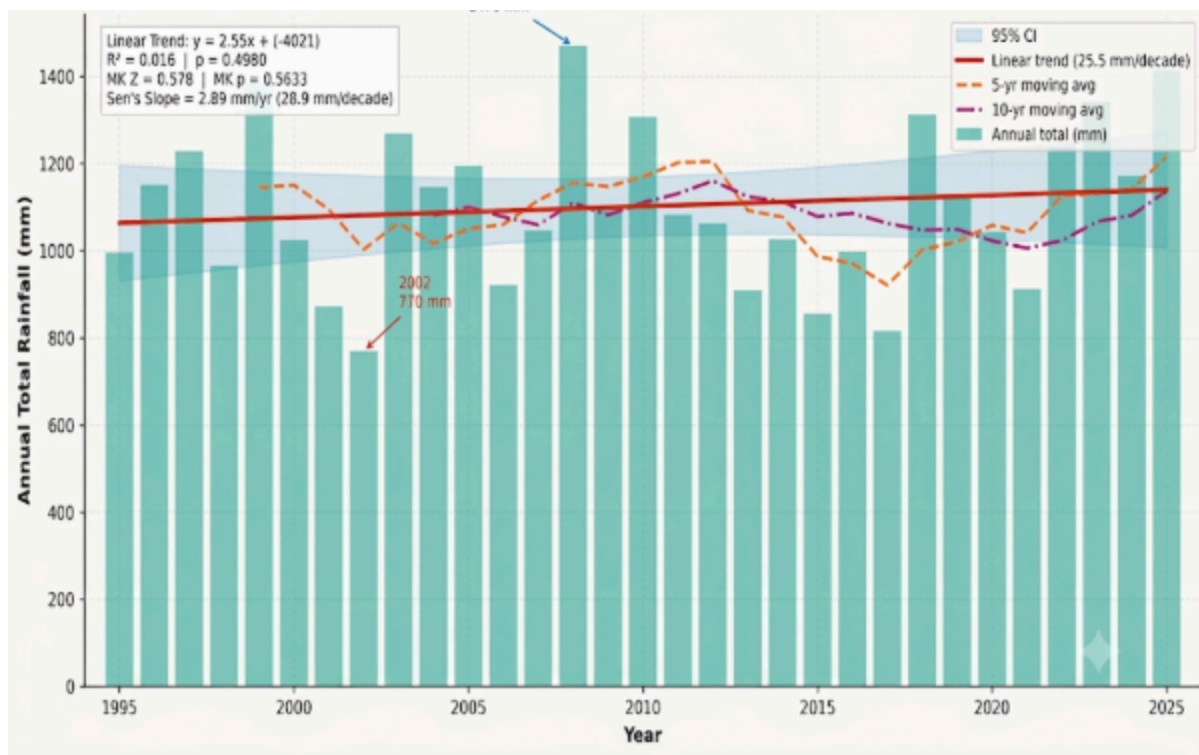


**Figure 3**

Annual rainfall pattern in the ORB from 1995 to 2025

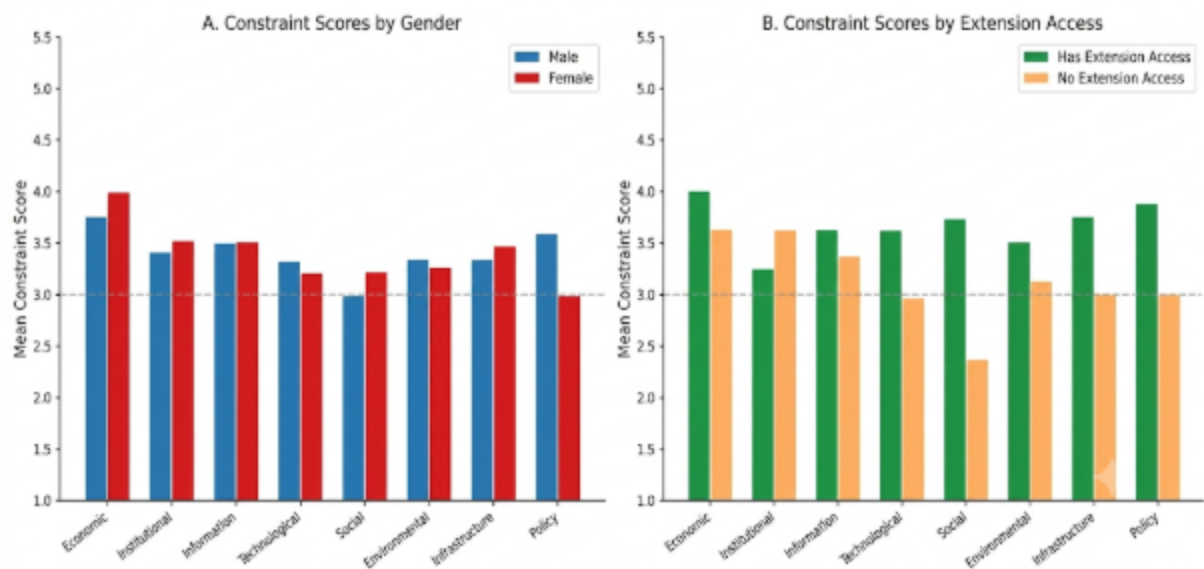


**Figure 4**

Constraint domain scores disaggregated by gender (Panel A) and extension service access (Panel B) among farmers in the basin

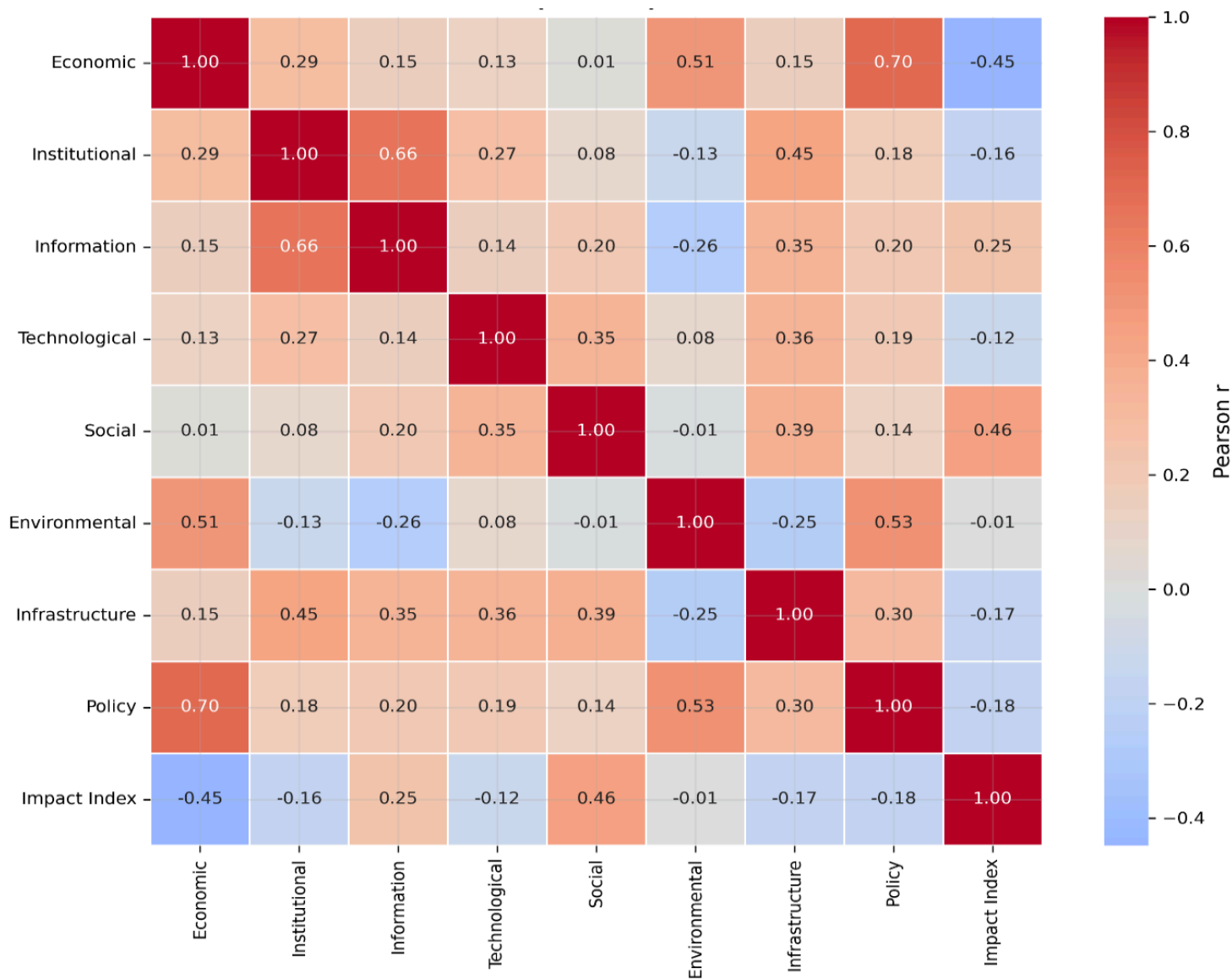


**Figure 5**

Figure 6. Correlation matrix of constraint domains and composite climate impact index.