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Effects of Climate Change Adaptation Practices on Rice Productivity: A Factor Analysis of Farming System Challenges in Northern Ghana

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Abstract

Background: Climate-related stresses, declining water availability, and escalating pest outbreaks are increasingly disrupting rice farming systems globally, threatening the food security and livelihoods of smallholder farmers. While farmers adopt various adaptation strategies to cope with these environmental shifts, the empirical effectiveness of these practices and the specific structural challenges hindering them remain inadequately explored. Understanding the nexus between adaptation and output is critical for building sustainable agricultural systems.

Objective: This study assessed the effects of climate change adaptation practices on rice production and identified the underlying challenges within rice farming systems in the Tolon and Kumbungu Districts of Ghana.

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Methodology: Utilising a multistage sampling technique, data were collected from 420 rice farmers via a semi-structured questionnaire deployed through the KoboCollect app. The research employed descriptive and inferential statistics, including multiple regression to measure the impact of adaptation variables on output, and factor analysis to categorise the multidimensional challenges faced by respondents.

Results: The findings indicate that the farming population is predominantly male (87.92%), with an average age of 40.1 years and low levels of formal education (73.34%). Multiple regression analysis (R^2 = 0.8353) revealed that several adaptive variables, such as the use of improved seed varieties, irrigation practices, and soil moisture conservation, have a positive and significant effect on rice output. Furthermore, factor analysis identified four primary challenges: institutional weakness, water scarcity stress, financial constraints, and climate vulnerability, which collectively accounted for 60% of the observed cumulative variance.

Conclusion: The study concludes that while adaptation practices significantly enhance rice productivity in Northern Ghana, the persistence of institutional and physical constraints undermines their overall effectiveness. The identified challenges necessitate a more robust framework for agricultural support.

Unique Contribution: This research integrates output-based regression with a multidimensional factor analysis to provide a comprehensive classification of farming challenges. It offers a clear indicator of the strength and direction of variables that impede sustainable rice production in sub-Saharan Africa.

Key Recommendation: The government and development partners should strengthen institutional policies to scale up climate-smart agricultural practices. Key interventions should include improving access to climate information, enhancing affordable credit facilities, and promoting community-based decision-making in the adoption of new agricultural technologies.

Keywords: adaptation practices, rice output, farmers' challenges, Ghana, factor analysis.

Introduction

Rice is a crucial staple crop grown globally, providing nourishment for over half of the world's population and playing a substantial role in Ghana's economy as both a major food source and a cash crop (Amfo et al., 2021). It contributes approximately 15% to Ghana's GDP (Danso et al., 2021) and is vital to food security, particularly in the northern region, where it is cultivated on a large scale (Ministry of Food and Agriculture [MoFA], 2020).

However, rice production is affected by challenges linked to climate variability, particularly in northern Ghana, including inadequate water access, soil erosion, pests and diseases, and inexperience and ineffective use of agrochemicals (Danso et al., 2021), among other challenges. Guodaar et al. (2021) reported that the impacts of climate change, especially in northern Ghana, manifest as rising temperatures, unpredictable rainfall patterns, droughts, floods, and shifts in planting seasons. It is evident that various authors have investigated climate change adaptation strategies and challenges in rice farming systems in Northern Ghana, including Opoku-Mensah et al. (2025), Osei Boateng et al. (2024), and Alhassan et al. (2023), among others. Despite numerous studies, there remains a lack of robust empirical

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evidence that comprehensively integrates and effectively examines the influence of these adaptation practices on rice output, and the multidimensional challenges in the rice farming system localised in the study area, a gap which this study seeks to address.

Methodology

Study Area

This study was carried out in the Tolon and Kumbungu Districts in Northern Region of Ghana, located on coordinates 9º25'51.6"N, 1º3'53.63" W. According to the Ghana 2021 Census, Tolon and Kumbungu Districts have populations of 118,101 and 110586 people, respectively. As described by Ayamga et al. (2018), the geography of the area composed of large low-lying plains with sporadic hills and ridges. The climate in the area is semiarid, with two distinct seasons, including the rainy season (June to September) and dry season (November to April), which substantially influence the local climate and water availability and operations of agricultural practices.

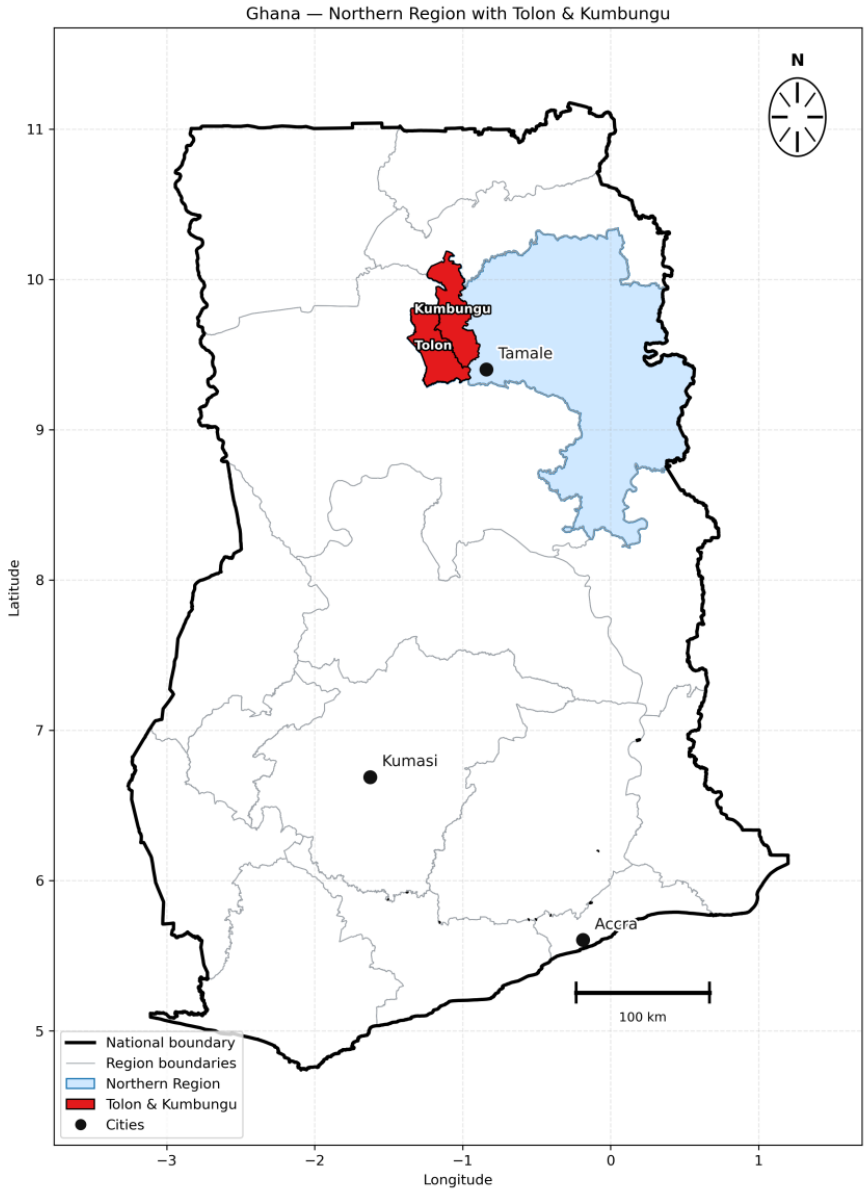

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Figure 1: Map of Ghana showing Tolon and Kumbungu in Northern Region

Population and Sampling Technique

The population for this study comprises registered rice farmers in the two districts. Based on the list of rice farmers sourced from the MoFA offices in the two districts, the total population of registered rice farmers was 2810. The study randomly selected 420 respondents based on a sample size estimate using Yamane's formula with a 4.5% error margin. Multistage sampling was employed for the study. In the first stage, the two districts were purposively selected due to the predominance of farming communities supported by the presence of the two irrigation schemes (Golinga & Bontanga Dams) in the area. In the second stage, 21 rice farming communities were randomly selected from the list obtained from the MoFA district offices. Thirdly, 420 respondents were randomly selected from the list of farmers across the 21 selected farming communities. The 4.5% error margin (e = 0.045) was considered suitable for the study because of its higher precision and robustness. A larger sample size enhanced the representativeness and reliability of the study population, while incurring the higher costs of field logistics and time during the survey. Using Yamane's Formula:

$$n = \frac{N}{1+N(e^2)} = \frac{2810}{1+2810(0.045^2)} = \frac{2810}{1+5.69025} = \frac{2810}{6.69025} = 419.8 \approx 420 \quad (1)$$

Where:

n = sample size
N = population size
e = error margin

Data Collection and Analysis

Data Collection: The study utilised primary data, collected via a semi-structured questionnaire administered through the KoboCollect app. The instrument was reviewed by experts in the Department of Environment and Sustainability Sciences at UDS Ghana, revised, and pretested on a sample of 20 farmers within the UDS community to ensure its clarity, validity, and reliability.

Data Analysis: The data were analysed using both descriptive and inferential statistics. The assessment of farmers' demographic characteristics was conducted using descriptive statistics, while multiple regression was employed to examine the relationship between adaptation practices and rice output (Kg), and factor analysis was utilised to identify and classify the multidimensional challenges in rice farming systems. Expression of ordinary least squares (OLS) regression:

a. OLS Multiple Regression (Scalar Form - explicit)

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \cdots + \beta_k X_{ki} + \varepsilon_i, \quad (2)$$
$$i = 1, 2, \ldots, n \ (n \ is \ no. of \ observations)$$

Where

Y_i = Total_Rice_Output (Kg/Ha)

β_0 = Intercept (Constant Term – the average rice yield without adaptation practices $X_1 = X_2 = 0$.)

β_j = Regression Coefficient - Slopes (Partial effect of adaptation practices j on rice output, i.e. a coefficient of X_1 minus change in Y when X_1 increases by 1 unit, holding X_2 constant) where $j = 1, 2, \ldots, k$, and k is defined as the number of independent (explanatory variables)

X_1 = Improved Seed Varieties (%)

X_2 = Irrigation Practices (%)

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X_3 = ASMT (0/1/2)
X_4 = Soil Moisture Conservation (%)
X_5 = Crop Diversification (No .of crops)
X_6 = Fertiliser Use (kg/ha)
X_7 = Water Harvesting (0/1)
X_8 = Agrofor. Practices (No. of Trees/Ha)
X_9 = Early Warning Systems (0/1/2/3/)
X_{10} = Crop Rotation (No. of Rotations/yr)
X_{11} = IPM (No.L/ha)
X_{12} = APD (% of Yield increase)
X_{13} = Extension Services Access (0/1)
X_{14} = Extension Visits (No. of Visit/yr)
X_{15} = CBDRR (0/1)
X_{16} = CSLMA (0/1)
ε_i, u_i = error terms

b. Exploratory Factor Analysis (EFA)

The Exploratory Factor Analysis (EFA) was employed to group and reduce numerous farmer challenges into fewer underlying dimensions. EFA identifies latent factors by examining correlations among observed variables.

Expression of the EFA model:

$$X_i = \Lambda f_i + \varepsilon_i, \qquad i = 1, \dots, n \tag{3}$$

$X_i = (x_{1i}, x_{2i}, \dots, x_{pi})'$: p x 1 vector of observed farmer-reported challenges for farmers i
$f_i = (f_{1i}, f_{2i}, \dots, f_{mi})'$: m x 1 vector of latent factors (underlying grouped challenges).
$\Lambda = [\lambda_{jk}]$: p x m factor loading matrix showing the relationship between observed and latent factors.
ε_i: p x 1 vector of unique errors/specific variances.

The implied covariance structure is given as:

$$\Sigma_x = \Lambda \Phi \Lambda' + \Psi \tag{4}$$

Where

Φ: covariance matrix of latent factors (identity if orthogonal, freely estimated if correlated).
Ψ: diagonal matrix of unique variances

Definition of observed & latent variables

p: number of observed variables (indicators)
m: number of common latent factors
n: sample size (number of observations)

Observed data (Farmers Challenges)

$X_i = (x_{1i}, x_{2i}, \dots, x_{pi})'$: Columns vector of observed measured variables for units i

x_1 : Access_to_Credit
x_2 : Cost_of_Farm_Inputs
x_3 : Land_Tenure_Insecurity
x_4 : Infrastructure_Quality
x_5 : Access_to_Modern_Equipment
x_6 : Market_Access_&_Price_Stability
x_7 : Education_&_Technical_Knowledge
x_8 : Impact_of_Climate_Change

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x_9 : Government_Policy_Effectiveness
x_{10} : Labor_Shortages
x_{11} : Post_Harvest_Losses
x_{12} : Agricultural_Extension_Support
x_{13} : Transport_Cost
x_{14} : Dependence_on_Rainfed_Agric
x_{15} : Water_Availability_for_Irrigation
x_{16} : Cost_of_Irrigation
x_{17} : Water_Competition_&_Conflicts
x_{18} : Access_to_Climate_Resilient_Seeds

Results And Discussion

Demographic Characteristics of Rice Farmers

The result in Table 1 revealed the distribution of demographic characteristics of rice farmers in the area. The findings indicated that the workforce is dominated by youth, with about 34.52% aged 30-39 years, followed by 20.48% who are middle-aged (40-49 years) and 20% who are aged 20-29 years. Additionally, 17.62% were older farmers aged 50-59 years, while only 6.67% were aged 60 years and above. This study indicated that farmers in the area have an average age of 40.1 years. Ayeh et al. (2025) reported that the mean age of rice farmers across Ghanaian municipalities was 45 years. Additionally, the study revealed a highly imbalanced gender distribution, with men 88% and women at only 12%. This gender disparity, with males being 7.2 times more numerous than their female counterparts, indicates an underrepresentation of women in rice farming, highlighting the need for gender sensitivity and equitable advances in agriculture by local agencies and ministries. Generally, in northern Ghana, underrepresentation of women in rice farming is not due to a lack of involvement, but rather to cultural and structural constraints. The customary system in the area confers land ownership and control on males, thereby restricting female-eligible farmers. In some communities, the patriarchal cultural norms limit female interaction with researchers and even extension agents without men's approval. Asante et al. (2023) reported that men (66.5%) outnumbered women (33.5%) in rice production in Ghana. The implication of this finding reflects the deeply rooted cultural settings of most typical Ghanaian rural communities, where men are the owners of the farms and, hence, tend to participate in more farm-related activities than women.

Additionally, the findings revealed that the majority (73.34%) of the farmers lacked education, while a small percentage (10.83%) had primary education, 11.25% had completed secondary education, and a few (4.58%) had acquired tertiary education. This lack of education can hamper the adoption of climate-smart agricultural practices and hinder access to climate information. Most of the farmers in the area cannot easily read or understand technical manuals or labels on improved seeds or other innovative farm inputs. These farmers find it difficult to access climate information, such as weather forecasts and early warnings, which are often presented in written or digital formats. As a result of high illiteracy, farmers may mishandle new technologies, miss early warning alerts, and implement adaptation strategies ineffectively, thereby reducing the effectiveness of climate-smart agricultural technologies.

This study also indicated that the majority (34.58%) of farmers had 6-10 years of farming experience, while a few (27.50%) had less than 5 years. This category with less experience

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was youthful and tended to be more open to adopting climate-smart agricultural technologies, but struggled to tackle climate variability independently. Another category, with 24.17%, had between 11 and 20 years of farming experience. The least category (13.75%) had the greatest years of farming experience, above 20 years. This category, with more years of farming experience, is elderly and tends to possess valuable indigenous knowledge, yet may resist adopting new farming techniques and climate-smart agricultural technologies. This result aligns with the findings of Agila and Kiraz (2025), who highlight that farmers with fewer years of farming experience adapt to climate change and agricultural risks.

Table 1: Distribution of the Demographic Characteristics of Rice Farmers

Demographic Characteristics		N=420	
Category	**Range**	**(%) 100**	**Mean**
Age	Below 20	0.71	
	20-29	20.0	
	30-39	34.52	
	40-49	20.48	
	50-59	17.62	
	60 and above	6.67	**40.10 years**
Gender	Female	12.08	
	Male	87.92	
Marital Status	Married	89.17	
	Single	6.67	
	Widowed	3.33	
	Divorced	0.83	
Education Level	No Formal Education	73.34	
	Primary Education	10.83	
	Secondary Education	11.25	
	Tertiary Education	4.58	
Years of Farming Experience	Below 5 years	27.50	
	Between 5-10 years	34.58	
	Between 11-20 years	24.17	
	Above 20 years	13.75	
Main Source of Income	Farming (Crops)	88.75	
	Trading and Commerce	3.33	
	Artisanship	2.08	
	Public & Private Sector Employment	2.08	
	Livestock	1.67	
	Farming (Unspecified Category)	1.25	
Income Level /Year (GHS)	<10,000	53.33	
	10,000-20,000	30.83	
	20,001-30,000	12.08	
	30,001-40,000	2.50	
	40,001-50,000	0.42	
	50,001-100,000	0.42	
	>100,000	0.42	

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Source: Field survey (2025)

Furthermore, the study revealed that crop farming (88.75%) is the primary source of income, and the majority (53.33%) of the rice farmers earn below GHS 10,000 per annum. It is evident that low-income farmers encounter many challenges in adapting to climate change due to limited resources, which restrict their access to improved seeds and better technology. Low income limits the farmer's ability to adopt new technologies and secure farm inputs such as fertilisers, improved seeds, irrigation facilities, etc. As a result, the farmers depend on traditional low-yielding practices, which constrain productivity and decline their adaptive capacity to sustainable and climate-smart agricultural practices.

Effects of Climate Change Adaptation Strategies on Rice Output

This study examined the effects of climate change adaptation practices on rice output in the study area. Four functional forms of the ordinary least squares regression model were employed in the analysis: linear, semi-log, double-log, and exponential. The exponential model was identified as the most effective and best-fit model, with an Adjusted R2 of 0.8287 and more significant predictors.

The findings in Table 2 revealed that improved seed varieties had a positive correlation with rice output, indicating that a 1% increase in the adoption of improved seed varieties will lead to approximately a 0.20% increase in yield, which is crucial for adapting to climate change by offering drought resilience and pest resistance. Improved seed varieties with traits such as early maturity, deep root systems, efficient water use, stress-tolerant physiology, and built-in resistance genes to insect and disease attacks could minimise yield loss and reduce pesticide use under drought and dry-spell conditions. Tolerance to several climatic stresses improves water-use efficiency and enhances crop yields and resilience to climate variability.

Table 2: OLS Regression Result Impact of Climate Change Adaptation Strategies on Rice Output

Variables	***Exponential (log(Y) = β0 + β1X1 + β2X2 + ...)***			
Y_Total_Rice_Output (Kg/Ha)	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	7.306e+00	1.283e-02	569.573	<2e-16***
X1_Improved_Seed_Varieties (%)	1.995e-03	8.535e-05	23.370	<2e-16***
X2_Irrigation_Practices (%)	1.576e-03	7.660e-05	20.571	<2e-16***
X3_ASMT (0/1/2)	1.792e-02	2.527e-03	7.092	5.97e-12***
X4_Soil_Moisture_Conservation (%)	1.079e-03	9.445e-05	11.419	<2e-16***
X5_Crop_Diversification (No.of_crops)	1.328e-02	1.419e-03	9.36	<2e-16***
X6_Fertilizer_Use (kg/ha)	5.485e-04	3.461e-05	15.849	<2e-16***
X7_Water_Harvesting (0/1)	2.927e-02	4.106e-03	7.130	4.68e-12***
X8_Agrofor._Practices (No.Tree/Ha)	4.613e-04	1.368e-04	3.371	0.000821***
X9_Early_Warning_Systems (0/1/2/3/)	8.598e-03	1.974e-03	4.356	1.69e-05***
X10_Crop_Rotation (No.R/yr)	4.882e-04	1.777e-03	0.275	0.783648
X11_ Integrated Pest And Disease Mgt IPM (No.L/ha)	9.214e-04	1.392e-04	6.618	1.16e-10***
X12_APD (% of Y.increase)	1.694e-03	2.419e-04	7.004	1.05e-11***
X13_Extension_Services_Access (0/1)	2.177e-02	4.085e-03	5.329	1.65e-07***
X14_Extension_Visits (No.V/yr)	1.874e-03	4.776e-04	3.923	0.000103***
X15_CBDRR (0/1)	2.026e-02	4.142e-03	4.892	1.45e-06***

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X16_CSLMA (0/1)	1.257e-02	4.393e-03	2.860	0.004450**
	Residual standard error: 0.04054 on 403 df.			
	R^2: 0.8353, Adjusted R^2: 0.8287			
	F-stat: 127.7 on 16 and 403 df			
	P-value; <2.2e-16			

Significant. codes: ***0.001, **0.01 *0.05 '.' 0.1
Source: Field survey (2025)

The study revealed that the use of irrigation practices and agro-soil moisture management techniques (ASMT) with a 1% increase correlated with approximately 0.16% and 1.79% increases, respectively, in rice yields, indicating the relevance of water management, soil fertility, and conservation in sustaining crop growth. Synergistically, irrigation practices and agro-soil moisture management techniques (ASMT) enhance productivity by ensuring a consistent water supply and soil moisture, thereby decreasing the effects of drought and dry spells and improving soil nutrient uptake. Nevertheless, requires higher input costs and skilled labour, with the potential threat of salinisation. Generally, these climate-smart interventions can increase productivity but require intensive water and input management. Antwi-Agyei et al. (2023) revealed that synergies and trade-offs associated with implementing climate-smart agriculture (CSA) interventions, especially irrigation and ASMT, may increase farm productivity.

Additionally, the finding revealed that crop diversification and agroforestry potentially increase rice yield at approximately 1.33% and 0.046%, respectively, holding other factors constant. Fahad et al. (2022) reported that crop diversification in agroforestry systems enhances crop, timber, and fodder productivity and generates higher yields than monocropping systems with the same crop species. Furthermore, the study revealed that an increase of one kg/ha in fertiliser application is associated with an approximately 0.05% increase in rice yield. This highlighted the need for effective nutrient management to enhance water use efficiency. Additionally, the findings revealed that a one-unit increase in the adoption or intensity of water harvesting practices is associated with an approximate 2.93% increase in rice yields, underscoring the need for intensification and efficient use. This suggests that rainfall is unpredictable and dry spells are frequent. Thus, rainwater harvested in dams during the rainy season is stored for supplementary irrigation during dry spells, particularly at critical crop growth stages like tillering and flowering, when properly managed by community farmers. Community-driven water management optimises water allocation, canal maintenance, and irrigation schedules, ensuring equitable and efficient water use during periods of scarcity. Synergistically, these strategies enhance water availability at low cost, reduce the risk of crop failure and stabilise the crop yields. López-Felices et al. (2023) opined that rainwater harvesting (RWH) systems are a feasible alternative to increase water resources for agricultural use, especially in areas where water availability is a limiting factor for agricultural development or compromises its sustainability.

The findings revealed that agroforestry practices, early warning systems, and crop rotation significantly influenced the rice yields. An additional tree was associated with an estimated 0.046% of increase in rice yield. A one-unit increase in adoption or effectiveness of the early warning systems was associated with an approximate 0.86% increase in rice yield. Similarly, an additional cycle of crop rotation led to an estimated 0.49% increase in rice yield. This finding indicated that planting trees within the farm areas, early climate information, and

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cycles of rotation improve crop yields, although the effectiveness may vary across practices and locations. Furthermore, the findings revealed that a one-unit increase in integrated pest and disease management is associated with a 0.09% increase in yield. To effectively adapt to climate-related issues, Andargie et al. (2024) noted the need for more research on the occurrence, distribution, current status, and yield losses of these diseases and pests, as well as further investigation into management options such as biological control, botanicals, and cultural practices.

Additionally, the findings revealed that a one-unit increase in the adjustment of planting date (APD) is associated with a 0.0169% increase in crop yield. This study suggests that synchronising crop development and growth with rainfall patterns is crucial, ensuring that critical stages of crop growth, such as germination, seedling establishment, vegetative growth, tillering, flowering, and grain filling, coincide with periods of sufficient moisture. Adjusting planting dates based on earlier or later rainfall onset could minimise the crop's exposure to drought and water stress, thereby enhancing yields in the area. Ismail et al. (2025) opined that adjusting planting dates will allow farmers to synchronise with climatic patterns, thereby mitigating drought stress, pests, and diseases during the essential growth stage, thus enhancing resilience to climate variability. Furthermore, the findings demonstrate that while access to extension services is associated with a significant 2.18% increase in crop yield, additional extension visits bolster rice yields by approximately 0.19%, highlighting the relevance of both coverage and extension regularity. This study suggests that strengthening extension services enables the timely dissemination and adoption of sustainable and improved technologies, such as the timely delivery of improved seeds and continual training and knowledge transfer, thereby increasing adoption rates and yields in the rice production system. Also, the study found that a one unit of community-based disaster risk reduction (CBDRR) and community-smart livestock management (CSLM) practices are associated with rice yield increases of approximately 2.03% and 1.26%, respectively, suggesting the potential of indigenous knowledge in decision-making processes in the adoption of sustainable practices and climate-smart agriculture.

Farmers Challenges to Climate Adaptation in Rice Production

The results of the factor analysis, indicating the challenges in rice farming, are presented in Figure 2, which shows a structural model as a factor-loading plot. Table 3 presents the statistical significance of the loadings, which define the latent dimensions of the farmers' challenges from the observed variables. The results of the factor analysis revealed four latent factors explaining 60% the total variance as presented in Table 3. These factors are statistically dependent on observed variables and their corresponding latent factors, with values ranging from 0 to 1.

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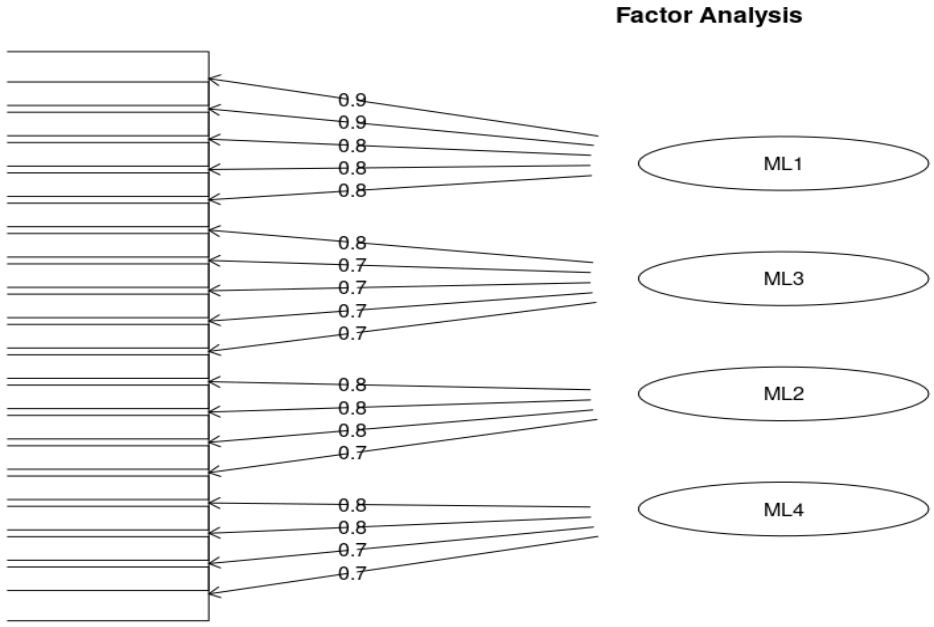

Figure 2: Diagrammatic Path showing the Result of Factor Analysis

The main identified primary factor was institutional weakness (ML1), representing infrastructure quality, access to modern equipment, farmer education, technical knowledge, effective government policy, and agricultural extension support, accounting for 19.8% of the variance, with loadings ranging from 0.8 to 0.9. Wudil et al. (2022) underscored that inadequate infrastructure and a lack of research funding complicate farmers' problems, necessitating the strengthening of institutions to help farmers cope with climate challenges in rice production. Water scarcity stress (ML2), the second main factor, is characterised by rain-fed agriculture, availability of water for irrigation, irrigation costs, and water-related conflicts, and accounted for 14.3% of the variation, with loadings ranging from 0.7 to 0.8. The financial challenges (ML3), the third key factor, are characterised by credit access, input costs, land tenure insecurity, market access, and transport costs, and accounted for 13.5% of the variance, with loadings between 0.7 and 0.8. As documented by Nkiwane et al. (2024), financial challenges such as a lack of access to credit and a high cost of inputs, among others, significantly affect the farmers' profitability and adaptive capabilities.

Table 3: Results of Factor Analysis for Farmers Challenges to Climate Adaptation

Challenges	factor loadings			cutoff=0.3
	Institutional Weakness	**Water Scarcity Stress**	**Financial Challenges**	**Climate Vulnerability**
	ML1	**ML2**	**ML3**	**ML4**
Access_to_Credit			0.695	
Cost_of_Farm_Inputs			0.737	
Land_Tenure_Insecurity			0.722	
Infrastructure_Quality	0.845			
Access_to_Modern_Equipment	0.837			
Market_Access_and_Price_Stability			0.759	
Education_and_Technical_Knowledge	0.813			
Impact_of_Climate_Change				0.736
Government_Policy_Effectiveness	0.857			
Labor_Shortages				0.744

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Post_Harvest_Losses				0.763
Agricultural_Extension_Support	0.856			
Transport_Cost			0.674	
Dependence_on_Rainfed_Agriculture		0.778		
Water_Availability_for_Irrigation		0.792		
Cost_of_Irrigation		0.746		
Water_Competition_and_Conflicts		0.791		
Access_to_Climate_Resilient_Seeds				0.757
Metric	**ML1**	**ML2**	**ML3**	**ML4**
SS Loadings	3.564	2.583	2.428	2.257
Proportion Variance	0.198	0.143	0.135	0.125
Cumulative Variance	0.198	0.342	0.476	0.600

Source: Field survey (2025)

Also, climate vulnerability (ML4), the fourth key factor, weighted the impact of climate change, labour shortages, post-harvest losses, and access to climate-resilient seeds, which accounted for 12% of the variance, with loading values ranging from 0.7 to 0.8.

Direction and Strength of Factor Loadings

The diagram in Figure 3 plots the direction and strength of factor-loading indicators contributing to key challenges affecting the rice production system. The institutional weakness ML1 (dark blue) shows strong loadings on variable indicators with high vulnerability due to limited institutional capacity. The water scarcity stresses ML2 (green) indicates loadings on variable indicators with vulnerability of farmers to water scarcity.

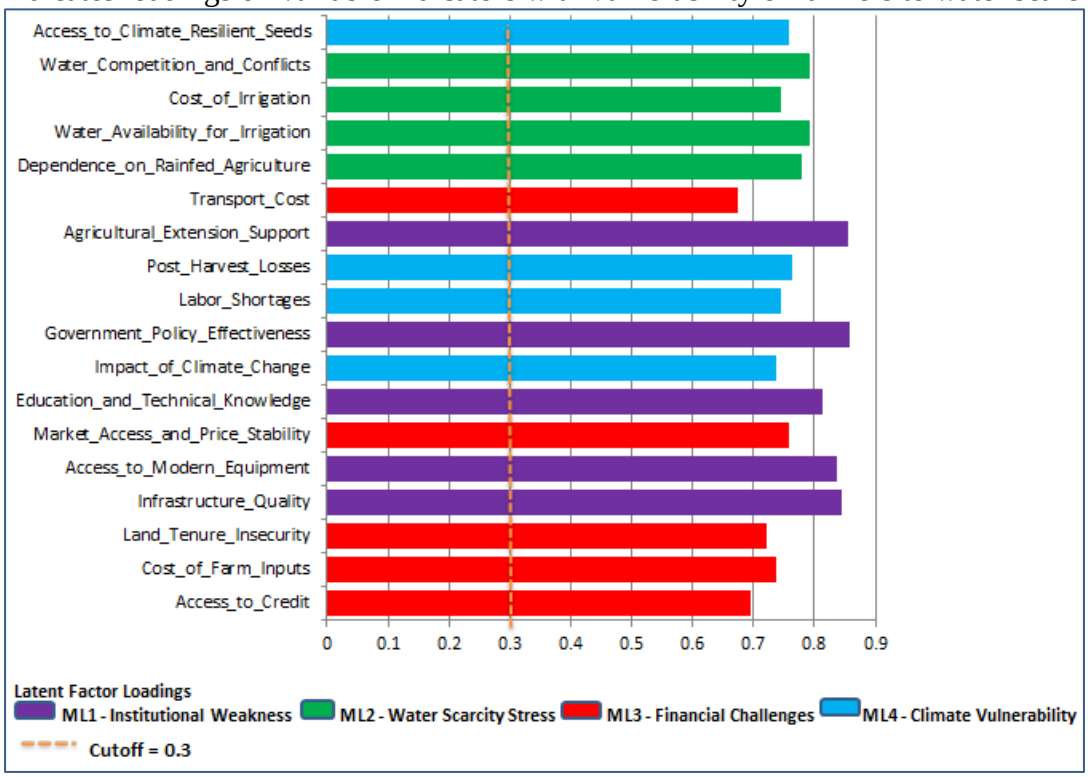

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Figure 3: Plot of Loading Indicators showing the Direction and Strength of Factors Contributing to Key Challenges

The financial challenges ML3 (red) demonstrates loadings on variable indicators with vulnerability driven by economic pressure. The climate variability ML4 (light blue) shows loadings on variable indicators contributing to climatic threat. Generally, ML1, ML2, ML3, and ML4 constitute multidimensional challenges that collectively increase the risk to sustainable crop production and the effective adoption of climate-smart technologies.

Conclusion And Policy Recommendations

Rice farming is a crucial occupation in the study area, enhancing the livelihoods of many households and supporting the national food security. The success of climate change adaptation strategies in the rice farming system is severely constrained by institutional weaknesses. Institutional weakness constrains research funding, leading to poor access to financial facilities, inadequate infrastructure such as dams, irrigation, and storage facilities, and the localisation of climate-smart agricultural technologies. Institutional weakness hinders the effective implementation of adaptation strategies, thereby declining their impact on crop yields. Strengthening institutions is fundamental to mobilising finance for research, improving infrastructure, and ensuring the adoption of climate-smart agricultural practices to cope with environmental challenges, including climate-related and water stresses, in rice farming. This would ensure the adoption of sustainable practices and adaptation strategies that would translate into a resilient crop farming system and stable crop yields. Addressing these challenges would strengthen adaptive capacity and enhance sustainable practices within the area's rice farming system. The study made the following key recommendations:

i. Government agencies (MoFA), partner institutions and NGOs strengthen technical policy challenges, training and capacity building of extension agents, and promote the adoption of climate-smart agriculture (CSA) with prerequisite interventions for climate resilience and adaptations.
ii. Ghana Meteorological Agency (Gmet), in collaboration with partners, should improve access and dissemination of climate information to the rice farmers.
iii. Financial institutions like the Agricultural Development Bank and other partners should enhance access to affordable credit, climate-responsive inputs and subsidies, and also encourage farmers to form cooperatives and community-based organisations to enhance access to credit facilities, inputs and markets.

Disclosures

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Authors' Contributions: T.D.U., B.N.B, & S.J.C. conceived and designed the study; T.D.U. performed the data collection; T.D.U. analysed the data; T.D.U. wrote the paper; B.N.B. & S.J.C. provided critical review and editing of the manuscript. All authors have read and agreed to the published version.

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