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Impacts of Climate-Induced Water Scarcity on Rice Production among Smallholder Farmers in the Northern Region, Ghana

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Abstract

Climate change has intensified water scarcity threatening rice production and food security in Northern Ghana. Despite the gradual increase in rainfall trends over short rainy seasons, the region is concurrently experiencing recurrent drought conditions and drastic reductions in water bodies, suggesting climate-induced hydrological imbalance. This paradox has raised concerns about the vulnerability of smallholder farmers and sustainability of rice farming in the region. This study assessed the impacts of climate-induced water scarcity on rice production among smallholder farmers in the Northern Region, Ghana using the mixed-method approach. Primary data were collected from 420 rice farmers using semi-structured questionnaire, while secondary data were obtained from reputable sources. Data were analyzed using geospatial analysis, descriptive and inferential statistics. The trends analysis showed increasing rainfall suggesting a disconnect between rainfall pattern and effective water availability. Additionally, minimum and maximum temperatures, and minimum relative humidity indicated upwards trends, while maximum relative humidity showed decreasing trend over the period (1990-2022). Spatio-temporal dynamics of land-use/land-cover changes (LULCC) between 2014 and 2024 showed significant expansion in settlement (63.62%) and cropland (19.23%), while a decline in vegetation (-25.06%), water bodies (-33.56%), and open-land (-5.29%), demonstrating rapid landscape changes over this period. The result showed that rainfall, minimum and maximum temperatures significantly influenced rice yields over the period (1990-2022). The study reveals a climate-agriculture paradox, where increasing rainfall does not translate into adequate water availability leading to recurring water scarcity. Climatic and environmental factors have significant influence on the farming systems, underscoring the need for effective adaptation practices. Strengthening regional stakeholder-led interventions on sustainable use of land and water resource, water-energy-food nexus, and strengthening irrigation systems would enhance agricultural output.

Keyword: Climate-induced, water scarcity, rice production, smallholder farmers, Ghana

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Introduction

In recent decades, changing climatic condition have become a key issue threatening food production globally, causing disruptions to the farming systems, and increasing the vulnerabilities in the society (Anshida, et al., 2026). Meran et al. (2021) reported that anthropogenic activities due to industrial revolutions have deepen the burning of the fossil fuels leading to accumulation of greenhouse gases in the atmosphere. The dynamics of landscape, climate variability and extremity in weather events (Ahmed *et al.*, 2025) are the immediate effects that interfere with long-standing agricultural practices. Heat stress caused by protracted droughts due to water scarcity can decline crop productivity, and make crops more susceptible to pest and diseases. In Ghana, climate change has become a grave hazard affecting economic activities and sustainable farming practices. These climatic changes including unpredicted rainfall, rising temperatures, droughts and flooding, have created a crucial agricultural paradox in which intense rainfall occur over a short period, followed by prolonged dry spell and droughts conditions, resulting into water scarcity, declined soil moisture, and consequently reduced crop yields. Therefore, this study aimed at investigating of the impacts of climate-induced water scarcity on rice production among smallholder farmer in Northern Ghana by analyzing climate variables trends, dynamics of LULCC, and climate factors and rice output relationship over time.

Methodology

The study was conducted particularly in the Tolon and Kumbungu Districts of Northern Region, Ghana, situated on coordinates between approximately 9º15'N-10º02'N latitude, and 0º53'W-1º25'W longitude. The study investigated the trends in climate variables (1990–2022), land use/ land cover changes from 2014-2024 using satellite imagery, and time series impacts of climate variability on rice yields using climate and rice output data (1990–2022).

Results and Discussions

Trends Detection in Climate Variables

The MK results on climate variable data from 1990 to 2021, as presented in Table 1, revealed key trends and patterns. The temperature (Tmin) showed positive correlation with a p-value of < 0.05, a Z-statistic of 174 and a Kendall's tau ($\tau = 0.350$). The Sen's slope estimate of 0.051 mm/ year, with a structural shift around year 2013. The temperature (Tmax) showed a p-value of 0.032 and a Kendall's tau ($\tau = 0.269$). The Sen's slope estimate of 0.029mm with a shift in 1997. The findings of Frimpong et al. (2023) indicated that changing temperatures, unpredictable rainfall have adverse impacts on the environmental surroundings in many metropolises in Ghana.

Table 1: Results of Mann-Kendall Trend Analysis

Statistic	**Rainfall**	**Tmin**	**Tmax**	**Wind Speed**	**Radiation**	**Sunshine**	**Rhmax**	**Rhmin**
Trend Direction	Increasing	Increasing	Increasing	Decreasing	Decreasing	Increasing	Decreasing	Increasing
Kendall Tau (τ)	0.28	0.35	0.27	-0.23	-0.17	0.163	-0.15	0.39
p-value (MK)	0.025	0.005	0.032	0.07	0.18	0.28	0.25	0.00195
Z-Statistic	139	174	133	-114	-83	1.091	-72	192
Sen's Slope	0.033	0.051	0.029	-0.0097	-0.013	0.06	-0.104794	0.33
Pettitt p-value	0.053	0.075	0.32	0.017	0.47	0.026	0.4900341	0.00015
Pettitt Change Year	2007	2013	1997	2014	2003	2017	2012	2002

Source: Filed survey (2025)

Quantification and Classification of Land Use and Land Cover Changes (2014-2024)

The results (Table 2 & Figure 1) of the classification accuracy assessment revealed a high reliability of LULC maps with an Overall Accuracy (OA) of 90.33% and a Koppa Coefficient (κ)

of 0.8594, demonstrating a significant correlation between the reference data and the classified images. The confusion matrix confirmed high reliability and user accuracy of cropland (92.54%) and vegetation (90.41%) in the mapped area, while water-body (50.00%) had the lowest accuracy. Settlement (80.95%) indicates moderate confusion with bare land (89.86%) and cropland. The results of the quantification and categorization of LULC showed that total area cover for the study was 2,854,483,200m^2. From 2014 to 2014, the settlement expanded by 63.62%, cropland expanded by +19.23, while vegetation decreased by -25.06. Bare land decreased by -5.29%, the water body decreased by -33.56% change, while the bare land decreased by -5.29% over the period. Population growth and rapid urban expansions have resulted in amplified demand for human needs such as housing, sport/event center, commercial space, infrastructure and residential places leading to changes in LULC.

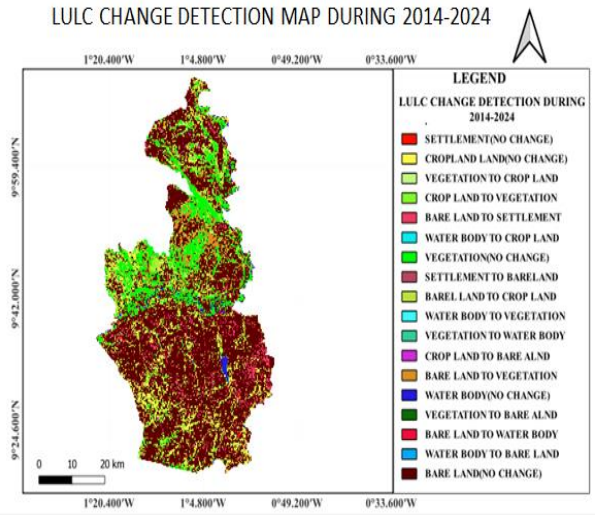


Figure 1: LULCC Detection Map during 2014 to 2024 (Source: Author's Construct, 2025)

Table 2: Classes and Quantum of LULCC from 2014 to 2024

Class	2014 Area (km²)	2024 Area (km²)	Change (%)	Actual Total	Classified Total	Correct	PA (%)	UA (%)	OA (%)	Kappa
Settlement	121.64	198.99	+63.62	21	23	17	80.95	73.91	90.33	0.8594
Crop land	1070.77	1277.30	+19.23	134	131	124	92.54	94.66	90.33	0.8594
Vegetation	928.18	695.05	-25.06	73	73	66	90.41	90.41	90.33	0.8594
Water Body	42.53	28.26	-33.56	3	4	2	66.67	50.00	90.33	0.8594
Bare Land	691.57	654.88	-5.29	69	69	62	89.86	89.86	90.33	0.8594
Overall	2854.48	2854.48		300	300	271			90.33	0.8594

Source: Field Survey, (2025)

Relationship between Climate Change and Crop (Rice) Yields

The findings of time series relationship between climate change and rice yields (ton/years) from 1990 to 2022 as presented in Table 3 revealed that the double log model showed a strong explanatory power as demonstrated in R^2 value of 0.803 and Adjusted R^2 value of 0.797 empirically confirming the explanatory power of the selected model. The findings revealed that, rainfall with estimated coefficient of 0.1012 suggesting a positive correlation of 1% increment would enhance rice yields by approximately 0.1012%. This finding aligns with the previous research of Baffour-Ata et al. (2025) who found that a positive relationship between annual rainfall and annual rice yields in Ghana. The temperature (Tmin) indicated a negative coefficient -0.6824 demonstrating that a 1% increment would decline rice output by approximately 0.6824% in the study area.

Table 3: Result of Double Log Regression

Variable	Double Log			
Y_Total_Rice_Output (ton/year) 1990-2022	CoefF.	std err	T	P-Value
Const	0.5	0.1	5.0	0.0001
Rainfall (mm) X1	0.1012	0.029	3.450	0.001***
Windspeed (m/s) X2	-0.1127	0.092	-1.230	0.22
Radiation (MJ/m2/day) X3	-0.0545	0.358	-0.152	0.879
Tmin (°C) X4	-0.6824	0.367	-1.860	0.064*
Tmax (°C) X5	0.8393	0.308	2.726	0.007***
RHmin (%) X6	-0.1465	0.156	-0.942	0.347
RHmax (%) X7	0.1721	0.194	0.888	0.375
Sunshine (hr) X8	0.0737	0.122	0.603	0.547
	Df Residual std error: 260 R^2: 0.803, Adjusted R^2: 0.797 F-stat: 132.4, p-value: 4.29e-87, AIC: 379.0, BIC: 407.7			

Source: Field Survey, (2025)

The temperature (Tmax) demonstrated positive coefficient of 0.8393 showing that a 1%increment would correlate with an approximate 0.8393% increase in rice yields. The wind speed, radiation, relative humidity (RHmin & RHmax) and sunshine were statistically not significant at the standard cutoff level ($p > 0.1$), demonstrating that the variables could not independently influence the yields of rice over time. The findings agree with Gyamerah et al. (2024) who found climatic variables including minimum and maximum humidity, rainfall, wind and sunshine statistically not significant to the cereal crop yields. This study underscored the need for adoption of water-conserving techniques such as controlled irrigation, aerobic rice farming, hydroponic seed propagation, and rainwater-harvesting to enhance resilience in rice farming and improve livelihoods and food sufficiency.

Conclusions and Outlook

This research underscored the complex interaction between climate change, water scarcity and rice production, highlighting peculiar interplay between increasing amount of rainfall, LULCC drivers, subsequent drought, and the resulting agricultural paradox in the study area. This ratifies that, beyond total annual rainfall, the timing and even distributions are among critical determinants of crop (rice) productivity. This study recommends that, government agencies in Ghana (Ministry of Food and Agriculture) and other partners should strengthen adoption of climate-smart agriculture, small-scale irrigation, and rainwater harvesting, community-based water management that can enhance dry-season farming and buffer against dry spells. Future research work should explore and strengthen water-energy-food (WEF) nexus integration and trade-offs to enhance efficient resource-use, sustainable production and climate resilience.

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