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Farmer's perceptions of climate change in semi-arid northwest Ghana: Implications for adaptation and resilience

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A R T I C L E I N F O

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A B S T R A C T

Climate change poses severe risks to smallholder agriculture and food security, particularly in semi-arid regions of sub-Saharan Africa. This study investigates farmers' perceptions of climate change and its implications for adaptation and resilience in Northwest Ghana, a highly vulnerable region with low adaptive capacity. Utilizing a mixed-methods approach, including a household survey of 2,107 farmers and qualitative data, the research bridges scientific climate data with local experiences. Findings indicate that most smallholder farmers perceive increases in temperature and the frequency of droughts and dry spells over the past 20-30 years. These perceptions align with long-term climate analyses revealing a steady increase in temperatures and a decreasing trend in inter-annual rainfall. Spatial analysis further highlights heterogeneities in these perceptions across districts, influenced by micro-climatic and geographic factors. This study provides a nuanced understanding of farmers' perceptions and the need for context-specific adaptation policies and strategies essential for bolstering adaptation and resilience in Northwest Ghana and similar regions.

1. Introduction

Climate change presents a considerable risk to farming systems and food security in the semi-arid areas of sub-Saharan Africa, where livelihoods are inextricably tied to rain-fed subsistence farming (IPCC, 2014; Yaro et al., 2015; Teye et al., 2021). In Northwest Ghana, a region characterized by low socioeconomic development and high vulnerability to climatic stressors, there is a pressing need to quantify the observed climatic changes over time and the nexus with local experiences and perceptions. This study presents a comprehensive analysis integrating instrumental climate data over the last six decades and household surveys to address this critical knowledge gap.

The overarching goal of this paper is to explore the interconnection between observed climatic changes and the experiences of smallholder farmers in semi-arid Northwest Ghana. Specifically, this paper seeks to answer two interrelated questions: 1) What are the observed trends and patterns in temperature and precipitation over recent decades in Northwest Ghana? 2) How are these climatic changes manifesting in the lived experiences and risk perceptions of smallholder farmers across the region? By interrogating these questions through a rigorous mixed-methods approach, the study generates critical insights to inform context-specific climate change adaptation policies and interventions.

A substantial body of literature has examined climatic changes in Northern Ghana. Studies have documented trends of rising temperatures (e.g., Eguavoen, 2013; Fagariba et al., 2018; Yaro et al., 2015) and declining precipitation (e.g., Antwi-Agyei et al., 2012; Antwi-Agyei & Nyantakyi-Frimpong, 2021; Owusu & Waylen, 2009) utilizing climate data and records from weather stations across the region. However, there remains a paucity of locally-specific data and analysis integrating instrumental records with farmers' lived experiences and autonomous adaptation practices. Addressing this gap is pivotal for developing tailored, context-specific climate change adaptation strategies that harmonize scientific knowledge with local realities and priorities (Teye et al., 2021; Dakurah, 2021). Additionally, while these works provide a broader climatic context and trajectories, they present a general macro-level analysis of climatic changes in northern Ghana. Thus, limiting our understanding of micro-climatic variations and site-specific impacts, which are of critical importance in regions with diverse topography and micro-environments. Importantly, microclimates are defining factors in the lived experiences of smallholder farmers who experience climatic hazards and crop failures.

Moreover, while previous research has generated rich insights into climatic trends, there has been relatively less emphasis on integrating these empirical observations with local knowledge systems and autonomous adaptation practices. This study, however, places a strong emphasis on the lived experiences of smallholder farmers who are at the forefront of coping with and responding to climatic stressors. By amplifying these lived experiences, we seek to inform holistic, context-specific adaptation strategies that harmonize empirical insights with local realities and priorities. This approach bridges the apparent epistemic divide between scientific climate data and farmers' risk perceptions, fostering a deeper understanding of the challenges faced by these communities.

This study combines instrument data from multiple weather stations with an extensive household survey (n=2,107) across seven districts in Northwest Ghana to capture farmers' observations, perceptions, and autonomous adaptation strategies. By bridging empirical climatic observations with local knowledge and experiences, this study provides a nuanced understanding of the complex nexus between environmental changes, agricultural vulnerability, and adaptation strategies in Northwest Ghana. This nuanced understanding, with its significant implications for policy formulation, climate-smart agricultural development, and the design of context-specific interventions, underscores the importance of bolstering the resilience of smallholder farming communities in the face of a changing climate.

The paper is organized as follows: the next section highlights the study area and research methods adopted, while sections 3 and 4 present the results and discuss them in the context of the literature. The paper concludes in section 5 with a reflection on the implications of the findings for adaptation and resilience building.

2. Study area and methods

This study focused on seven districts in Northwest Ghana: Sissala East, Wa East, Daffiama Bussie Issa, Nandom, Lambussie Karni, Wa West and Sawla-Tuna-Kalba (Figure 1). Northwest Ghana exemplifies the climate vulnerability challenges faced in sub-Saharan Africa, characterized by a semi-arid climate with a single rainy season typically spanning from April to September. The area records an average annual rainfall of 900-1100mm (Ghana Meteorological Agency, 2020). supporting a landscape dominated by Guinea Savannah vegetation on predominantly flat terrain. The socioeconomic fabric of this region is complicatedly tied to its environmental conditions. Approximately 90% of households depend on rain-fed agriculture as their primary livelihood, a dependence made precarious by limited irrigation infrastructure (Ghana Statistical Service, 2018). This reliance on seasonal rainfall renders the population acutely susceptible to both short-term weather fluctuations and long-term climate shifts, creating a complex context of vulnerability.

Figure 1: Study district maps in the context of Ghana. Source: Authors own construct.

Intensifying these environmental challenges, the region contends with significant socioeconomic barriers. It ranks among Ghana's most impoverished areas, with poverty rates surpassing 70% in some districts (Ghana Statistical Service, 2018). This current struggle is rooted in a historical context of underdevelopment, shaped by colonial-era neglect and post-independence governance issues (Jarawura et al., 2024). The intersection of climate change with these pre-existing vulnerabilities presents a multifaceted challenge for local communities, demanding evidence-based and context-specific adaptation strategies.

2.1 Methods

To capture the complexity of climate change perceptions, impacts, and adaptation strategies in this vulnerable region, this study employed a mixed-methods approach. This study design comprises a quantitative scope with qualitative depth, providing a comprehensive understanding of the challenges faced by local communities (Patton, 2014).

The quantitative data for this study consisted of a structured questionnaire administered to 2,107 households between May and August 2022. This instrument was crafted through an extensive literature review and refined through pilot testing in a non-study community (n=50), ensuring its validity and reliability in capturing local realities. The questionnaire delved into a range of themes, from demographic and socioeconomic characteristics to livelihood strategies, climate change perceptions, observed environmental changes, adaptation strategies, and access to climate information. To minimize bias and ensure cultural sensitivity, we enlisted local enumerators fluent in local languages, providing them with rigorous training on survey administration and ethical considerations.

Seven districts across two administrative regions were selected to ensure representativeness across the diverse landscape of Northwest Ghana. A simple random sampling approach was adopted with the aim of reducing selection bias. The sample shows a fair distribution across genders, with females making up 47.56% and males 52.44% of the 2,107 sample size. This almost equal split indicates that the sample is broadly representative in terms of sex ratios. More than half (53.77%) of respondents have no formal education, indicating very low levels of educational capital. Only 1.43% hold post-secondary, vocational, technical certifications or academic degrees. Household sizes are generally large, with an average of around 8 members. The most common household size is 5 members (15.14%), but over 70% have 5 or more members, and nearly 5% have 15 or more. This indicates a trend towards extended, multigenerational living arrangements. Livelihoods are predominantly agrarian, with 68.39% deriving income from food crop production, highlighting the economic landscape. Smaller percentages are involved in cash crops (7.02%), petty trading (7.78%), livestock rearing (5.32%), and artisanal work (2.23%). Formal sector salaried employment is minimal at 3.89%. The high concentration in subsistence agriculture indicates a high vulnerability to poverty (Derbile et al., 2016; Dakurah, 2021). There are significant barriers to accessing climate information, with 48.08% reporting no access and another 10.11% uncertain. However, 41.82% report at least intermittent access, suggesting some dissemination of these resources into rural populations.

Complementing this quantitative approach, we carried out a qualitative analysis within the sample. The qualitative data collection provided evidence-based data and contextual insights into the lived experiences of climate change. We conducted 30 in-depth interviews, equally divided between men and women. Farmers who had lived and farmed in the community for at least the last twenty years were selected for interviews. These farmers have experiential knowledge of the pattern and nature of climatic changes over time. These semi-structured conversations allowed for the exploration of personal narratives and local knowledge systems. Additionally, we facilitated 15 focus group discussions, carefully segregated by gender to ensure open dialogue, each comprising 10-15 participants spanning ages 20 to 85. This age range captured both historical perspectives and contemporary experiences of environmental change. Finally, 14 local government authorities were interviewed, fairly distributed across the seven districts, to gain further information on local perceptions and government responses.

2.2 Estimation techniques

Logistic regression model

The study employed the binary logistic model in analysing data from 2093 respondents. The sample size was reduced by 14 because of multicollinearity. The binary logistic regression is appropriate due to the binary nature of the outcome variable (the perception that temperature/ rainfall is increasing or otherwise). Let P_i^* Represent the perception of increasing temperature or decreasing rainfall and βX_i Represent a vector of explanatory variables that determine the respondent's perception of temperature and rainfall.

The model is specified in Equation 1

$$P_i^* = \beta X_i + \varepsilon_i \qquad eqn1$$

Where $P_i = 1$ if the perception of temperature is increasing and if the perception of rainfall is decreasing, and 0 if otherwise.

A reference category was chosen for each of the categorical variables.

Data triangulation

For qualitative data, thematic analysis was employed, following the approach outlined by Miles et al. (2014). Through iterative team discussions, we refined emerging themes, ensuring they authentically represented the voices and experiences of our participants. To enhance the validity of our findings, we employed triangulation across our quantitative and qualitative data sources, cross-referencing insights to build a coherent and comprehensive understanding. We further validated our interpretations through member checking with key informants, ensuring our conclusions resonated with local realities. This methodological approach, blending rigorous quantitative analysis with rich qualitative insights, allowed us to paint a nuanced picture of climate change perceptions and adaptations in Northwest Ghana.

3. Results and discussion

3.1 Nature of climatic changes in northwest Ghana

The seasonal temperature variations in the region exhibit distinct patterns, as evidenced by the analysis of weather station data from Wa, the capital city of the Upper West Region. During the boreal winter, also known as the harmattan season (December, January, and February), minimum and mean temperatures are generally lower compared to the March-April-May (MAM) season. This phenomenon can be attributed, in part, to the cooling effect of atmospheric dust particles during the harmattan season. Dust net radiative forcing is negative, indicating that atmospheric dust aerosols contribute to a cooling effect on the climate, resulting in lower temperatures even in the absence of cloud cover (Knippertz & Todd, 2012).

Notably, the monthly minimum temperature reaches its lowest point during December and January, subsequently increasing from January and peaking in April. Following this peak, the minimum temperature begins to decline from May onward. The warmest period of the year is typically the MAM season, characterised by the highest maximum temperatures, as shown in Figure 2 (a). These elevated temperatures can be attributed to the scarcity of clouds and reduced concentrations of dust particles, which would otherwise contribute to a cooling effect. However, as May approaches, temperatures begin to decrease due to the increased presence of cloud cover, which exerts a cooling influence.

During the months of June-July-August, mean and maximum temperatures are further reduced, reaching their minimum in August (Figure 2 b and c). This phenomenon can be attributed to the combined effects of cloud cover and the intensification of the moist and cool South Westerly (SW) winds originating from the ocean during this season (Nicholson et al., 2000). Consequently, the lowest mean and maximum temperatures are observed during the rainy season. As the strength of the SW winds diminishes and the amount of cloud cover decreases during the September-October-November (SON) period, mean and maximum temperatures begin to rise again from September, reaching a secondary peak in November.

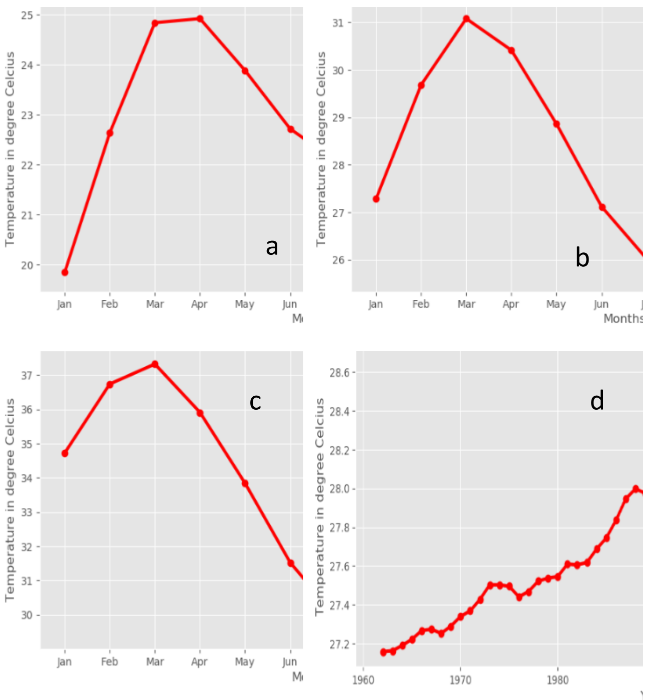

Figure 2: a) Wa monthly minimum temperature variation, b) Wa monthly mean temperature variation, c) Wa minimum temperature variation, d) Wa inter-annual mean temperature variation (10-year moving averages). Source: Authors' construct based on data from the Ghana Meteorological Agency.

Furthermore, the analysis of inter-annual mean temperature variations over Wa reveals a general trend of increasing temperatures over time (Figure 2 (d). The region has been experiencing a steady rise in temperatures across various measures, with the maximum and minimum temperatures exhibiting comparable upward trends. The maximum temperatures, representing the highest points reached, have been rising at a rate of 0.028°C per year. This upward trajectory in maximum temperatures signals the intensification of heat extremes, potentially exacerbating the challenges faced by smallholder farmers and local communities during the warmest periods. In a similar vein, the minimum temperatures, which mark the coolest points of the cycle, have also been increasing, though at a slightly higher rate of 0.029°C per year. The consistent rise in both maximum and minimum temperatures suggests that the entire temperature spectrum is shifting upwards, leaving little respite from the mounting heat stress. The mean temperature, which reflects the average thermal conditions over a given period, has been increasing at the same rate as maximum temperatures, 0.028°C per year. This consistent rise in mean temperatures, mirroring the trends observed in maximum and minimum temperatures, underscores the region's overall warming trajectory, with implications for various sectors and ecosystems that are sensitive to changes in average climatic conditions (Dinko & Bahati, 2023; Nyantakyi-Frimpong, 2020).

3.1.1 Inter-annual rainfall variability

An examination of inter-annual rainfall variability in the Upper West Region of Ghana reveals a decreasing trend over recent decades. Quantitative analysis of rainfall records in Wa indicates a decrease of 0.30 mm per year from 1953 to 2020 (Figure 3a). This finding aligns with previous studies that have documented a consistent downward trajectory in rainfall amounts across Ghana (Owusu & Waylen, 2009; Aniah et al., 2019), suggesting a broad-scale drying pattern on an inter-annual timescale in this region.

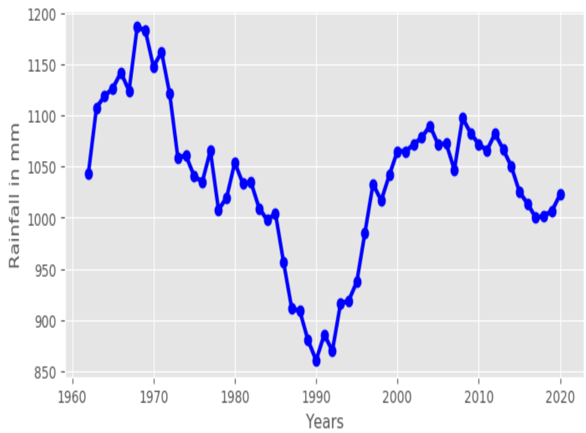

Figure 3. Wa inter-annual rainfall variation (10-year moving averages). Source: Authors' construct based on data from the Ghana Meteorological Agency.

Observed drying trend carries significant implications for the region's water resources, agricultural productivity, and ecological systems. Diminished rainfall can lead to water scarcity, depleted soil moisture reserves, and an increased propensity for drought conditions, adversely impacting crop yields and threatening food security (Ayanlade et al., 2018; Dinko, 2022; Gizaw & Gan, 2017; Grillakis, 2019). Furthermore, reduced precipitation can disrupt the delicate balance of ecosystems, potentially driving biodiversity loss and environmental degradation. Anthropogenic climate change, driven by increasing greenhouse gas concentrations and land-use transformations, represents a potential contributing factor, as it can perturb atmospheric circulation patterns and precipitation dynamics (IPCC, 2021; Knippertz & Todd, 2012; Okonkwo et al., 2015). Additionally, regional factors such as land degradation, deforestation, and alterations in aerosol loading may modulate rainfall patterns through complex feedback mechanisms (Knippertz & Todd, 2012).

Notably, the inter-annual rainfall variability in the region exhibits a distinct decadal oscillation pattern. For instance, in Wa, a positive rainfall anomaly was observed from the mid-1960s to the mid-1970s, followed by a negative anomaly phase from the mid-1980s to the mid-1990s. Subsequently, a positive rainfall anomaly re-emerged from the mid-2000s to the mid-2010s. This decadal oscillation bears a striking resemblance to the AMO, a prominent mode of natural variability characterized by multi-decadal fluctuations in North Atlantic Sea surface temperatures. (Yang et al., 2020).

Emergent literature has established a robust connection between the AMO and rainfall variability in the Sahel region. (Knight et al., 2006; Mohino et al., 2011; Zhang & Delworth, 2006). During positive phases of the AMO, when North Atlantic Sea surface temperatures are anomalously warm, the Sahel region tends to experience higher-than-average rainfall. (Knight et al., 2006; Okonkwo et al., 2015). Conversely, during negative AMO phases, characterized by cooler North Atlantic temperatures, the Sahel typically experiences drier conditions. This teleconnection may contribute to the observed decadal modulation of rainfall patterns in Northwest Ghana, highlighting the influence of large-scale oceanic-atmospheric processes on regional precipitation dynamics.

The observed decreasing rainfall trends and decadal variability patterns in the Northwest have profound implications for the livelihoods, environmental sustainability, and resilience of local communities. Reduced precipitation severely undermines agricultural productivity, exacerbating food insecurity and socioeconomic vulnerabilities, particularly in regions heavily dependent on rain-fed agriculture. Furthermore, dwindling water resources can strain domestic and agricultural water supplies, potentially exacerbating conflicts over scarce resources and impeding socio-economic development. This has cascading effects on essential ecosystem services, such as water regulation, soil fertility, and carbon sequestration, further compounding the challenges faced by local communities.

3.2 Farmers' perception of climate change

3.2.1 Temperature changes

The majority (81.7%) of respondents interviewed in the study districts indicated that the intensity of temperature had increased over the last 30 years. *The temperature has increased a bit from the time we were young men to the moment that we are old men, and we still depend on farming, so it is a problem,* explains an aged man during a male focus group discussion. Although respondents generally agreed to an increase in temperature, some argued that the increase began around 1984, after the 1980-1983 devastating droughts. *If you want to understand the temperature in this area, you must look beyond the years of serious hunger (the droughts of 1980-1983) when we started to feel little increases from that time till now*, explains a queen mother of one of the study communities. The proportion of respondents holding the perception of an increase in temperature, however, varied across the districts, ranging from 60.5% of the respondents in the Sissala East Municipality to 96.4% of the respondents in the Wa East District. This perception is consistent with the long-term temperature analyses presented earlier. The perceived increase in temperature aligns with the inter-annual mean temperature variations over Wa, as depicted in Figure 2, and the trend analysis of temperature from synoptic weather stations in the Upper West Region (Fagariba et al., 2018). Increasing temperature has direct implications for crop yield and, consequently, the long-term resilience of smallholder farmers. For example, using 30 years of historical weather data, crop characteristics, and management practices to stimulate MacCarthy et al., (2021), estimate a reduction in maize grain yield by up to 20% between 1980 and 2010, in semi-arid regions in West Africa.

3.2.2 Occurrence and intensity of drought

The results of the study show that many (71.6%) respondents, irrespective of their sex (as equal proportions of both sexes, 71.6% each), indicated that the occurrence of drought over the last 20 to 30 years is increasing. Except for the Sissala East Municipality (where most (96.3%) of the respondents held contrary views to increasing drought occurrence), the majority (over 70%) of the respondents in the other study districts indicated that drought has been increasing. This disparity could be explained by the more forested nature of the Sissala East district. The district holds large portions of the two national forests and game reserves, the Gbelle Reserve and the Mole Game Reserve. These two are highly forested and provide better micro-climatic conditions, including rainfall (Ghana Statistical Service, 2012).

The general perception of the increasing occurrence of droughts is consistent with the climate data analyses presented earlier, which show high variability with significant decreases in rainfall in the 1970s, 1980s, and between 2010 and 2020. The IPCC (2019) observes that climate change-induced droughts have become more common in arid and semi-arid areas such as the Upper West Region of Ghana. Droughts often set off a chain of crop failure, poverty, and migration. (Jarawura & Smith, 2015; Liehr et al., 2016; Nyantakyi-Frimpong & Dinko, 2022), and environmental degradation, as smallholder farmers, in their quest to survive, inadvertently adopt negative environmental practices such as charcoal production (Brida et al., 2013). Droughts may cause stress by making water inaccessible and unusable through contamination, compromising health and affecting short-term coping strategies and long-term adaptive capacity and resilience of households (Bola et al., 2014; Calow et al., 2006).

3.2.3 Occurrence of dry spells

Like drought, most (83.8%) of the farmers interviewed assert that the frequency of dry spells over the past 30 years is increasing. A few (3%) of them, however, claimed that dry spells were decreasing, while the rest (6.9%) indicated that it was the same. The proportion of farmers who indicated that dry spells are increasing varied across sexes (84.9% of males and 82.5% of females) in the seven study districts. It ranged from 60.5% in the Nandom Municipality to 97.7% in the Daffiama/Bussie/Issa District. This perception of increasing dry spells is not only consistent with the climate analyses presented earlier, which show high inter-annual variability, but also with various climatic studies across West Africa. For example, Soeters et al. (2016) observed an increased frequency of dry spells and a shift in the start of the rainfall season. Similarly, Tachie-Obeng et al. (2014) confirm the Ghana Environmental Protection Agency's (EPA, 2000) findings that the onset of the rainy season has shifted, while the rains are now more intense and unpredictable.

3.2.4 Occurrence of flood

Most respondents in Wa West (43.7%), Sissala East (45.5%), Lambussie-Karni (37%), Daffiama/Bussie/Issa (DBI) (42.4%), and Sawla Tuna Kalba (40.7%) districts indicated that the occurrence of floods over the last 20 – 30 years is the same. In Wa East (46.7%) however, most respondents said floods are decreasing. In the Nandom District, as high as 39.3% of respondents also claimed that floods are decreasing. In all districts, some respondents reported an increase in floods - 37.1% in Wa East, 18.8% in Nandom, 16.0% in Daffiama/Bussie/Issa, 13.7% in Wa West, 12.0% in Lambussie/Karni, 8.3% in Sawla Tuna Kalba, and 7.6% in Sissala East. An elderly man explained the nature of the increase in flooding in the following words:

> "The problem with floods is that it is only a growing problem for those communities close to the rivers and those farmers who farm in the lowlands. In those days (in the 1970s and 1980s), it was a blessing to farm the lowlands in this village, but we have learned many lessons from perennial flooding, which does not seem to be ending, so we know where to farm the crops that do not require plenty of water. We all know it is mainly rice that survives this flooding, but not crops like maize." (Elderly Man, FGD).

Many focus groups and interviews shared this view of flood occurrence and vulnerability. While farming in the valleys is a crucial adaptation measure to rainfall variability, it can increase the risks of flooding. In many ways, these findings echo the literature on exposure and vulnerability to climate-induced flooding, which shows that the ability of smallholders to respond to climate risk is circumscribed by alternating bouts of floods and droughts (Egyir et al., 2015; Asante et al., 2012; Kuriakose et al., 2009).

3.3 Spatial analysis of perceived climate change impacts across the study areas

Figure 4a) depicts the perceived percentage increase in temperature across the districts. A striking observation is the relatively homogeneous spatial pattern, with most districts falling within the highest category of a 90.01-96.00% perceived temperature increase. This suggests a widespread perception of substantial temperature rises throughout the region. However, a few districts, such as Sissala East and parts of Nandom and Lambussie, exhibit slightly lower perceived temperature increases in the 77.01-90% range, indicating some localized variations in perception.

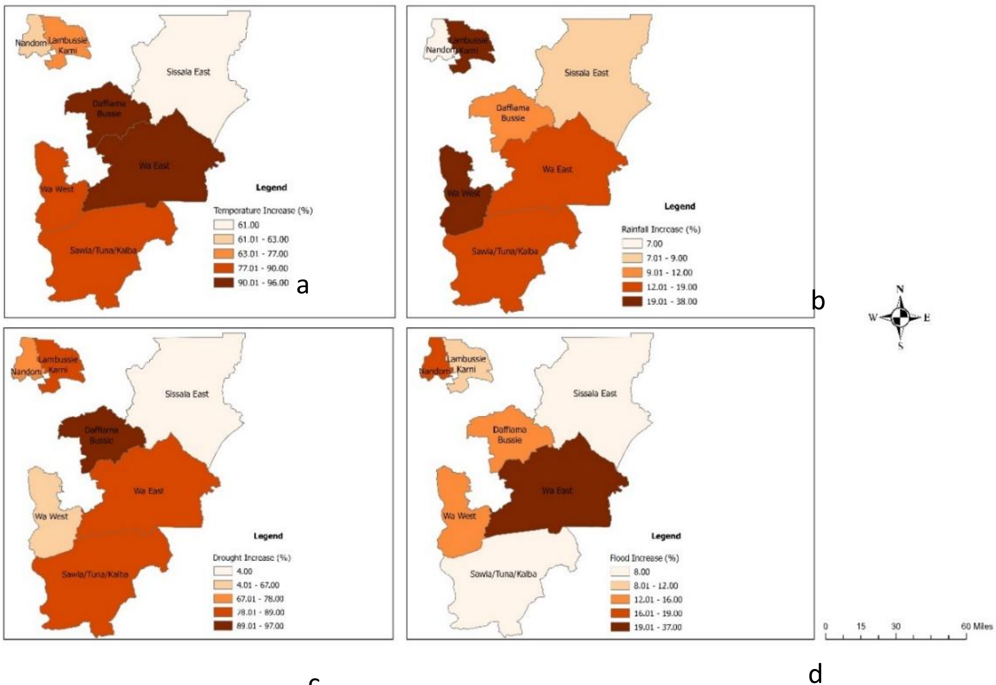

Figure 4: Spatial Analysis of Perceived Climate Change Impacts Across Districts in the Northwest. Source: Authors' construct based on REACH-STR survey data

Ghana: a) the percentage of respondents indicating an increase in temperature, b). The percentage of respondents indicating an increase in rainfall c). The percentage of respondents indicating an increase in drought d). The percentage of respondents indicating an increase in floods. Source: Authors' construct based on data from the Ghana Meteorological Agency.

The rainfall map (Figure 4 b) displays a more heterogeneous spatial pattern compared to the temperature map. The districts exhibit a broader range of perceived rainfall increase percentages, from as low as 7-7.90% to as high as 19.01-30.00%. This variability suggests that the perception of rainfall changes is more localized and diverse across the region. Interestingly, the district with the highest perceived rainfall increases (19.01-30.00%), such as Wa West and parts of Sawla/Tuna/Kalba, are not necessarily contiguous, indicating potential micro-climatic or geographic factors influencing these perceptions.

The drought map (Figure 4c) reveals a relatively uniform spatial pattern, with most districts falling within the highest category of a 78.01-89.00% perceived increase in drought conditions. This pattern is like the temperature increase map, suggesting a widespread perception of substantial drought intensification across the region. However, a few districts, like Sissala East and parts of Nandom and Lambussie, exhibit lower perceived drought increases in the 67.01-78.00% range, aligning with their slightly lower perceived temperature increases.

The flood map (Figure 4d) displays the most heterogeneous spatial pattern among the four maps. The perceived increase in flooding ranges from as low as 8% in some districts to as high as 19.01-37.00% in others. This variability in perceptions could be influenced by localized factors such as topography, drainage systems, or historical flood events. Notably, the districts with the highest perceived flood increases (19.01-37%), like Wa West and parts of Daffiama Bussie, do not necessarily align with the districts exhibiting the highest perceived rainfall increases, suggesting potential complexities in the relationship between rainfall and flood perceptions.

Overall, the temperature increase and drought increase maps exhibit relatively homogeneous spatial patterns, indicating a widespread perception of substantial increases in these climatic variables. The rainfall and flood maps display more heterogeneous spatial patterns, suggesting localized variations in the perceptions of these variables, potentially influenced by micro-climatic or geographic factors. While some districts, like Sissala East and parts of Nandom and Lambussie, consistently exhibit lower perceived changes across multiple variables, others, such as Wa West, exhibit contrasting perceptions- for example, high flood increases but not necessarily high rainfall increases. The spatial patterns of perceived changes do not always align perfectly across the variables, indicating potential complexities in how different climatic factors are perceived and experienced within each district. This spatial analysis highlights the value of examining perceptions at a granular level. It reveals localized variations and potential drivers of these perceptions, which is essential in informing targeted adaptation and mitigation strategies tailored to each district's specific needs and experiences.

3.4 Determinants of perceptions of climate change

Determinants of perceptions among farmers are crucial for interventions and climate strategies (Yaro, 2013; Jarawura, 2021). We further examined, on a general scale, the factors that are influential in local perceptions of climate change. In Table 1, the results of the binary logistic regression suggest that several factors significantly influence perceptions of rainfall changes over the past 20 to 30 years. These factors include marital status (monogamous and polygamous), education level, migrant status, production of cash crops, household access to land, participation in VSLA/Savings group, and access to climate information.

Table 1: Determinants of perceptions on changes in rainfall

Perceptions of changes in rainfall	Odds ratio	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
Sex	1.072	.116	0.64	.52	.867	1.325	
Age	.997	.004	-0.75	.455	.989	1.005	
Marital status:		.	.	.	.	.	
Base: cohabitation	1						
Divorced	6.626	8.874	1.41	.158	.48	91.449	
Married (monogamous)	9.408	11.937	1.77	.077	.782	113.123	*
Married (polygamous)	13.687	17.536	2.04	.041	1.111	168.611	**
Separated	6.497	9.537	1.27	.202	.366	115.378	
Single (Never married)	8.09	10.344	1.64	.102	.66	99.152	
Widowed	9.829	12.599	1.78	.075	.797	121.209	*
Education:		.	.	.	.	.	

Base: bachelors	1						
HND	1.022	.708	0.03	.975	.263	3.976	
JSS / JHS / Middle school	.541	.269	-1.23	.217	.204	1.435	
Master's or higher degree	.306	.349	-1.04	.299	.033	2.853	
No education	.425	.208	-1.75	.08	.163	1.108	*
Non-formal education	.741	.477	-0.47	.642	.21	2.616	
Nursery	.493	.443	-0.79	.432	.085	2.873	
O /A level / SSS /SHS	.523	.265	-1.28	.202	.194	1.414	
Primary	.431	.216	-1.68	.092	.161	1.149	*
Vocational / Technical/Professionals	.469	.246	-1.45	.148	.168	1.309	
Migration status:		.	.	.	.	.	
base First-generation migrant	1						
Indigene	1.192	.235	0.89	.372	.81	1.755	
Second-generation migrant	1.596	.43	1.73	.083	.941	2.708	*
Religion		.	.	.	.	.	
base Christianity	1						
Islam	.7	.078	-3.20	.001	.563	.871	***
Traditional	.883	.232	-0.47	.636	.528	1.478	
Income sources		.	.	.	.	.	
base Artisans	1						
Keeping of large livestock	1.331	.644	0.59	.555	.515	3.437	
Keeping small livestock	2.015	.993	1.42	.155	.767	5.295	
None	.625	.342	-0.86	.391	.214	1.828	
Others	.99	.439	-0.02	.982	.415	2.361	
Petty Trading	1.588	.66	1.11	.266	.703	3.588	
Production of cash crops	6.854	3.449	3.83	0	2.557	18.375	***
Production of food crops	.856	.322	-0.41	.679	.409	1.789	
Salaried worker	1.005	.467	0.01	.991	.405	2.497	
Cultivated land	1	.004	0.09	.926	.993	1.007	
Household access to land	1.006	.002	3.09	.002	1.002	1.009	***
Land ownership:		.	.	.	.	.	
Base: Extended family	1						
Household	.619	.066	-4.50	0	.503	.763	***
Neighbour	.928	.338	-0.20	.838	.455	1.894	
Other	13.961	9.036	4.07	0	3.926	49.642	***
The Chief	1.678	.561	1.55	.122	.871	3.232	
Land tenure		.	.	.	.	.	
base Inherited	1						
Other	.438	.141	-2.57	.01	.233	.822	**
Outright purchase	3.159	2.524	1.44	.15	.66	15.123	
Sharecropping	1.74	1.011	0.95	.341	.557	5.433	
Short-term lease	.678	.211	-1.25	.211	.369	1.247	
Leadership role	.727	.116	-1.99	.046	.532	.994	**
Group membership		.	.	.	.	.	
Base: other	1						

VSLA / Savings group	.799	.081	-2.22	.027	.655	.974	**
Access to climate information		.	.	.	.	.	
Base: No	1						
Not sure	.604	.105	-2.90	.004	.429	.849	***
Sometimes	.636	.074	-3.91	0	.507	.798	***
Yes	.674	.123	-2.17	.03	.472	.963	**
Constant	.809	1.137	-0.15	.88	.052	12.711	

Mean dependent var	0.658		SD dependent var	0.475
Pseudo r-squared		0.084	Number of obs	2107
Chi-square		180.864	Prob > chi2	0.000
Akaike crit. (AIC)		2569.203	Bayesian crit. (BIC)	2829.198

*** p<.01, ** p<.05, * p<.1

After controlling for other factors, the analysis reveals that individuals in monogamous and polygamous marriages are 9 and 14 times more likely, respectively, to perceive a decrease in rainfall compared to those who are cohabiting. Additionally, widowed women are 10 times more likely to perceive a decrease in rainfall, while second-generation migrants and individuals involved in cash crop production are 2 and 7 times more likely, respectively. Furthermore, respondents who own land from other sources are 14 times more likely to perceive a decrease in rainfall.

Table 2: Determinants of perceptions on temperature change

Variables	Odds ratio	St. Err.	t-value	p-value	[95% Conf	Interval]	Sig
Sex	1.274	.163	1.89	.059	.991	1.638	*
Age	.984	.005	-3.26	.001	.975	.994	***
Marital status:		.	.	.	.	.	
base: cohabitation	1						
Divorced	7.906	12.963	1.26	.207	.318	196.617	
Married (monogamous)	1.43	1.748	0.29	.77	.13	15.701	
Married (polygamous)	2.465	3.053	0.73	.466	.218	27.926	
Separated	2.767	4.436	0.64	.525	.12	64.054	
Single (Never married)	1.495	1.852	0.32	.746	.132	16.959	
Widowed	2.357	2.947	0.69	.493	.203	27.338	
Education:		.	.	.	.	.	
base: bachelors	1						
HND	.539	.411	-0.81	.418	.121	2.404	
JSS / JHS / Middle school	.817	.488	-0.34	.735	.254	2.631	
No education	1.025	.604	0.04	.967	.323	3.251	
Non-formal education	10.92	12.819	2.04	.042	1.094	109.008	**
O /A level / SSS /SHS	.959	.588	-0.07	.946	.289	3.189	
Primary	.65	.39	-0.72	.472	.201	2.104	
Vocational / Technical/Professionals	.805	.504	-0.35	.729	.236	2.746	
Migration status:		.	.	.	.	.	
base First-generation migrant	1						
Indigene	.523	.152	-2.23	.026	.295	.925	**
Second-generation migrant	.249	.085	-4.06	0	.127	.488	***

Religion		.	.	.	.	.	
base christianity	1						
Islam	.737	.098	-2.31	.021	.569	.955	**
Religion	1.237	.428	0.61	.539	.627	2.439	
Income sources		.	.	.	.	.	
base artisans	1						
Keeping of large livestock	4.77	3.899	1.91	.056	.961	23.675	*
Keeping small livestock	1.089	.633	0.15	.884	.348	3.404	
None	1.862	1.487	0.78	.436	.389	8.911	
Others	1.418	.803	0.62	.538	.467	4.304	
Petty Trading	1.06	.528	0.12	.906	.399	2.816	
Production of cash crops	2.272	1.214	1.54	.125	.797	6.476	
Production of food crops	.726	.326	-0.71	.476	.301	1.75	
Salaried worker	.891	.501	-0.20	.838	.296	2.684	
Cultivated land	1.003	.004	0.74	.457	.995	1.011	
Household access to land	.999	.002	-0.47	.635	.995	1.003	
Land ownership:		**.**	**.**	**.**	**.**	**.**	
Base: extended family	**1**						
Household	.862	.113	-1.13	.257	.668	1.114	
Neighbour	.352	.165	-2.22	.026	.14	.883	**
Other	1.359	.93	0.45	.654	.356	5.195	
The Chief	.558	.22	-1.48	.139	.258	1.208	
Land tenure	1	.	.	.	.	.	
base inherited	1.362	.601	0.70	.483	.574	3.232	
Other	1.953	2.291	0.57	.568	.196	19.454	
Outright purchase	3.628	2.758	1.69	.09	.817	16.102	*
Sharecropping (Type)	1.265	.515	0.58	.564	.569	2.81	
Leadership role	.857	.171	-0.77	.439	.58	1.267	
Group membership		.	.	.	.	.	
base: other	1						
VSLA / Savings group	1.568	.194	3.64	0	1.231	1.999	***
Access to climate information		.	.	.	.	.	
base: No	1						
Not sure	.856	.178	-0.75	.454	.569	1.287	
Sometimes	.993	.135	-0.05	.956	.76	1.296	
Yes	1.959	.532	2.47	.013	1.15	3.336	**
Constant	9.849	14.171	1.59	.112	.587	165.248	

Mean dependent var	0.817	SD dependent var	0.387
Pseudo r-squared	0.064	Number of obs	2107
Chi-square	107.337	Prob > chi2	0.000
Akaike crit. (AIC)	1955.736	Bayesian crit. (BIC)	2204.175

*** p<.01, ** p<.05, * p<.1

In Table 2, the key factors influencing perceptions of temperature include gender, age, non-formal education, indigenous status, second-generation migrant status, ownership of large livestock, neighbour's land ownership, outright land purchase, membership in a VSLA/Savings group, and access to climate information. Respondents with non-formal education are approximately 11 times more likely to perceive a temperature rise compared to those with bachelor's degrees. Individuals who purchased their land outright are 4 times more likely to perceive a temperature increase compared to those who inherited land. Members of a VSLA/Savings group are 2 times more likely to perceive a temperature change compared to individuals in other groups. Lastly, those with access to climate information are 2 times more likely to perceive a temperature change compared to those without access. The importance of the range of socio-cultural factors in determining perceptions of temperature highlights the need to give attention to different social groups when formulating planned adaptation strategies. This is crucial as perceptions have a great influence on the decisions and actions of adaptation (Grunblatt et al., 2017; Jarawura et al., 2024). Recognizing the varying perception among social groups can therefore lead to more effective adaptation (Nelson et al., 2023).

4. Conclusion and policy implications for resilience-building

The findings from this study are significant as they reveal the complex interplay between climatic shifts, experiences and perceptions, and agricultural vulnerability among smallholder farmers in Northwest Ghana. The overreliance on rain-fed subsistence agriculture renders these communities acutely susceptible to the impacts of climate change, underscoring a critical need to build resilience and improve adaptation capacity. The empirical evidence depicts a region grappling with rising temperatures and declining rainfall patterns. The steady increase in maximum, minimum, and mean temperatures, coupled with the decreasing inter-annual rainfall trends, portends significant implications for agricultural productivity, water resources, and ecosystem integrity. These climatic changes exacerbate existing vulnerabilities, posing grave threats to water and food security, livelihoods, and the overall resilience of rural communities. Diminished crop yields and water scarcity not only imperil the livelihoods of smallholder farmers but also exacerbate poverty, malnutrition, and health risks, thereby perpetuating a vicious cycle of vulnerability (Bola et al., 2014; Liehr et al., 2016). Furthermore, these climatic stressors could trigger environmental degradation, as resource-constrained communities may resort to unsustainable practices, such as charcoal production, to meet their immediate needs (Brida et al., 2013; Dinko et al., 2024; Jarawura et al., 2024).

Notably, the observed decadal oscillations in rainfall patterns, reminiscent of the Atlantic Multidecadal Oscillation (AMO), highlight the influence of large-scale oceanic-atmospheric processes on regional precipitation dynamics. This underscores the intricate web of connections that shape local climate patterns, necessitating a holistic understanding of these processes to inform effective adaptation strategies. The farmers' perceptions align with the empirical climatic analyses, with the majority acknowledging an increase in temperature intensity and the occurrence of droughts and dry spells over the past two to three decades. This convergence between climatic observations and local experiences not only enhances the internal validity of the findings but also underscores the urgency of addressing these challenges.

In the face of these climatic stressors, smallholder farmers have not just survived but demonstrated remarkable resilience by adopting a range of adaptation strategies. Changing planting dates emerges as the predominant approach, reflecting farmers' efforts to synchronize their agricultural activities with shifting precipitation patterns. Other strategies, such as the use of climate-resilient seeds, crop diversification, and engagement in non-farm activities, underscore the multifaceted nature of adaptation pathways. However, the study also reveals the limitations faced by farmers, with a significant proportion reporting no measures to cope with floods, highlighting the need for comprehensive adaptation support and capacity-building initiatives. Addressing these gaps is crucial to enhancing the adaptive capacity of rural communities and safeguarding their long-term resilience.

The findings from this paper have implications for adaptation and resilience planning in semiarid Ghana and beyond. Firstly, the convergence of local perceptions and metrological data analysis emphasises the urgency of participatory processes in the design and implementation of locally specific adaptation and resilience strategies. A critical aspect of addressing this need is the recognition of the value of local perceptions and their integration into national and local adaptation plans and strategies. It is equally important that policies and strategies are designed to flexibly engage with local perceptions that do not concur with modern scientific evidence. Such instances would require further research rather than their outright dismissal in policy and strategy formulation. Further, attention needs to be placed on local priorities as suggested by the heterogeneities in perceptions across districts,

Secondly, the study underscores the necessity of investing in climate-smart agricultural practices, such as the development and dissemination of drought-tolerant and heat-resistant crop varieties and the promotion of sustainable soil and water management techniques. Furthermore, the integration of traditional ecological knowledge with modern scientific insights can inform these context-specific adaptation strategies that are culturally relevant and locally appropriate (Nyantakyi-Frimpong et al., 2022). These interventions can enhance the resilience of agricultural systems, bolstering water and food security and livelihoods in the face of climatic adversities. Thirdly, the findings highlight the importance of strengthening early warning systems, improving access to climate information, and fostering effective communication channels between institutions and rural communities. Empowering farmers with timely and accessible climate data can facilitate informed decision-making and enable proactive adaptation measures. Finally, the study underscores the need for integrated rural development strategies that encompass livelihood diversification, capacity-building programs, and the promotion of climate-resilient infrastructure. By addressing the multidimensional challenges faced by smallholder farmers, these holistic approaches can enhance their adaptive capacity and contribute to the long-term sustainability of rural livelihoods.

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