Journal of Environmental Studies and Sciences
https://doi.org/10.1007/s13412-024-00970-w

RESEARCH AND THEORY

Climate risks and adaptation strategies: the perspectives of farmers in coastal Ghana

Johnson Ankrah[1,2]

Accepted: 6 July 2024

Abstract

The significance of farmers' perceptions of climate risks, particularly in developing countries with limited capacity for adaptation, is equally important as the actual impacts, considering the increased risks posed by global climate change. This study examined smallholder farmers' perceptions of climate risks and adaptation strategies in coastal Ghana using a mixed-methods approach. A multi-stage sample technique was used to survey 800 farmers, and 8 farmers were selected as key informants through interviews in the coastal Savannah agroecological zone. Existing climatological records were analysed using the Kriging interpolation technique, and farmers' adaptive capacity was predicted using binary logistic regression. The results revealed a substantial increase in farmers' climate change knowledge. The majority of the farmers perceived increased temperatures (100%) and decreased total annual rainfall (64%), along with an increase in wind speed (100%) across the zone. The farmers revealed that extreme temperatures, drought, and decreasing rainfall result in the ripening of unmatured crops, the drying of crops, a decrease in crop yield, and farm losses. The farmers recognised poverty (75%) and food insecurity (23%) as the main effects of climate risks. The farmers have employed various adaptation strategies, including cultivating different types of crops (46%) and planting improved seed varieties (18%). However, financial constraints (48%) and high costs for farm inputs or fertilisers (32%) hinder these strategies. Farmers' age, gender, education, and years of farming significantly predicted their decisions to adopt various adaptation strategies. Policy initiatives on subsidised farm inputs are required to safeguard the farmers' activities and enhance their livelihoods.

Keywords Climate change · Climate variability · Adaptation · Risk perception · Agriculture

Introduction

Climate change and variability continue to pose significant risks to all life forms (Solomon et al. 2007), making them one of the most pressing concerns of the twenty-first century (Easterling 2007). Climate change and variability have an impact on global temperatures, precipitation, and other essential factors such as wind speed (Célestin et al. 2019). According to the Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (AR5), global mean surface air temperature increased by 0.85 °C (0.65 °C to 1.06 °C) between 1880 and 2012, with a further projected increase of 0.3 °C to 4.8 °C between 2081 and 2100 in comparison to 1986–2005 (Bindoff et al. 2013). Global temperatures are projected to increase, as are precipitation and wind speed (Célestin et al. 2019). Changes in global precipitation follow a pattern in which wetter regions remain wetter and drier parts remain drier (IPCC 2007). Wind speed is projected to increase in many northern hemisphere regions, as well as in the tropics and subtropics (Akinsanola et al. 2021; Zha et al. 2021), as is the frequency of extreme events (Hounkpè et al. 2022).

Climate change and variability pose risks to all sectors of the global economy, particularly agricultural activity and food security (Ayeni and Adewumi 2023; Aydinalp and Cresser 2008; Brink et al. 2023). Several studies have highlighted climate change and variability risks to agricultural activities on the continental scale (e.g., Aryal et al. 2020; Steffen et al. 2011; Zhang et al. 2023) and on the

✉ Johnson Ankrah
ankrah.johnson1992@yahoo.com

[1] Faculty of Arts and Humanities, Geography Department, University of Porto, Via Panorâmica Edgar Cardoso, 4150-564 Porto, Portugal

[2] Centre of Studies in Geography and Spatial Planning (CEGOT), Geography Department, University of Porto, Porto, Portugal

Published online: 17 July 2024

global scale (Calzadilla et al. 2013; Wang et al. 2018) and their related effects on farmers' livelihoods (Tieminie et al. 2023). Despite this, the situation for farmers in developing countries, particularly those in Sub-Saharan Africa (SSA), whose agricultural activities are rain-fed and climate-sensitive and who rely solely on farming for their livelihoods, is dire (Batungwanayo et al. 2023; Hounnou et al. 2023; IPCC 2014; Naab et al. 2019). Temperatures in SSA are projected to increase, and rainfall will be erratic, potentially leading to a decrease in crop productivity, threatening food security, and affecting agricultural livelihoods (IPCC 2014).

Risk perceptions and knowledge among farmers regarding climate change and variability are thus critical for the application of appropriate adaptation strategies (Ricart et al. 2023; Yaro 2013). Ricart et al. (2023) describe risk perception as the way by which people receive information or stimuli from their surroundings and convert them into psychological awareness in order to act or react appropriately. Ado et al. (2019) argued that increased knowledge is critical in the initial stages of the adaptation process to reduce climate change and variability impacts and susceptibility because awareness levels reflect a community's level of exposure to climate-related risks. Yaro (2013) emphasised that communities whose livelihoods depend on natural resources are aware of their surroundings and are able to detect climatic inconsistencies and their consequences. As a result, Yaro (2013) stressed that local knowledge and perceptions of climate change and variability should form the basis of agricultural policies in a bottom-up manner and not just a mere acknowledgement by policymakers, as perceptions define adaptation outcomes. Risk perceptions and knowledge of farmers with varying characteristics are thus critical for designing practical adaptation plans (Yaro 2013). The implementation of proactive measures across geographic locations are required to adapt to the consequences of climate change and variability (Christensen et al. 2007). As a result, proper and precise risk perception is crucial for planned adaptation actions, as poor risk perception may result in maladaptation (Barnett and O'Neill 2010; Johnson et al. 2023), increasing farmers' susceptibility to climate change and variability, whereas proper risk perception may positively affect the adaptation process (Ricart et al. 2023; Yaro 2013).

Numerous research studies have been conducted on climate risk perception in various countries, including Ado et al. (2019), Batungwanayo et al. (2023), Chaachouay and Zidane (2024), Fahim and Sikder (2022), Hossain et al. (2022), Hubertus et al. (2023), Kabir et al. (2022), Shah et al. (2023), Smith (2018), Smith and Mayer (2018), Tasnim et al. (2023), and Wheeler et al. (2021). These studies recognise the significant role of climate risk perception in adaptation. Several studies in Ghana have also explored climate risk perception and adaptation strategies, with studies conducted by Antwi-Agyei et al. (2017), Asravor (2018), Fosu-Mensah et al. (2012), Lawson et al. (2020), Naab et al. (2019), Ntim-Amo et al. (2022), Sadiq et al. (2019), Tambo and Wünscher (2017), Yamba et al. (2019), Yaro (2013), and Yiridomoh et al. (2021). Notwithstanding insights gleaned from these studies, they focus solely on smallholder farmers' activities in the mid-to-northern half of Ghana. However, no research has examined smallholder farmers' perceptions of climate risks and strategies for adaptation in coastal Ghana, particularly those located in the coastal Savannah agroecological zone. Therefore, conducting research of this nature is necessary to bridge this information gap and improve understanding of farmers' perceptions of climate risks and their decision-making process for adaptation in Ghana.

The aim of this study is to examine smallholder farmers' perceptions of climate risks and adaptation strategies in the coastal Savannah agroecological zone of Ghana, a zone where there is currently a lack of research on this topic. Specifically, the study seeks to examine: (i) the perceived knowledge and causes of climate change and variability among smallholder farmers; (ii) the perceived climate risks that smallholder farmers face in their farming activities; (iii) the spatial distribution of annual variations and trends in climatological records in the zone and whether they support farmers' perceptions; (iv) the adaptation strategies employed by smallholder farmers to mitigate climate risks; and (v) predicting the odds of smallholder farmers choosing specific adaptation strategies using the binary logistic regression test.

This study not only contributes to the current literature on farmers' perceptions of climate risk but also has the potential to provide insights for the formulation of efficient adaptation strategies that aim to safeguard the livelihoods of smallholder farmers in the zone. Furthermore, this emphasises the potential and additional benefits of enhancing the climatological literacy of farmers, as well as the significance of informal knowledge in the field of science.

Literature review

The continuous warming of the global climate, which is primarily caused by negative anthropogenic activities (IPCC 2022; Karl and Trenberth 2003), is expected to endure for an extended period of several centuries (Karl and Trenberth 2003). Based on the findings of Karl and Trenberth (2003), the main cause of global climate change can be attributed to the alteration of atmospheric composition resulting from human activities. According to the IPCC's AR6, it is evident that the negative impacts of anthropogenic climate change and related extreme events on people and the environment are far greater than the inherent variability observed in natural climate patterns (IPCC 2022). According to Célestin et al. (2019), there is a projected increase in global temperatures and precipitation. The projected change in climate

poses significant risks to several sectors of the global economy, with particular emphasis on the agricultural sector (Hitz and Smith 2004). Furthermore, the potential impacts extend to the interrelated food systems, as emphasised by the IPCC's AR6 (IPCC 2022). The potential consequences of global warming on food security due to climate change have been highlighted in previous studies (Calzadilla et al. 2013; Wheeler and von Braun 2013). This could result in adverse effects such as hunger, malnutrition, and nutrient deficiencies, particularly in the vulnerable regions of the Global South that have limited or no adaptation measures (IPCC 2022). The situation is worse for Africa (Tirado et al. 2015) and the Sub-Saharan African (SSA) region in particular (Adesete et al. 2023; Liu et al. 2008). For example, Sylla et al. (2016) assert that the climate in West Africa has been warming as a result of its response to harmful anthropogenic greenhouse gas forcing. According to the IPCC's AR5, the West African region experienced a warming of 0.3 °C to 1.0 °C during the current decade (Bindoff et al. 2013). Sylla et al. (2016) reported that there is a projected rise in temperature, while precipitation in the region exhibits increased variability. The current circumstances have the potential to result in a higher frequency of extreme events, such as droughts and floods, which are characteristic of the climatic conditions in the region (Ekwezuo and Ezeh 2020). The findings of Gebrechorkos et al. (2019) showed that the East African region has warmed and rainfall has become more variable. According to Niang et al. (2014), rainfall in East Africa has greater inter-annual variability, which is characterised by devastating extreme events such as drought and floods (Haile et al. 2020). The climate change situation in Southern and Central Africa is no different from that in East Africa (Niang et al. 2014). Temperatures have increased and rainfall has become variable in Southern Africa (IPCC 2019; Kapuka et al. 2022). In most areas of Southern Africa, the IPCC (2019) projects increased extreme temperatures and wildfire incidence in drier summers. Southern Africa's subtropical locations anticipate a decrease in rainfall (Archer et al. 2017; Kapuka et al. 2022). Research studies such as those of Aloysius et al. (2016) and Mba et al. (2018) have highlighted the warming and variable rainfall in the Central African region.

Sani and Chalchisa (2016) reiterate that climate change poses severe impacts on agriculture in SSA, which has a substantial number of smallholder farmers. Agricultural production in most of the countries in SSA is climate-sensitive, which makes them vulnerable (Brügger 2020; Omotoso et al. 2023). The impacts of climate change on agriculture in SSA pose a significant challenge for the sustainable development of the region and the entire African continent (Juana et al. 2013). Notwithstanding the increased impacts of climate change on agricultural production in the SSA, research studies such as those by Juana et al. (2013) and Mertz et al. (2009) have established that most farmers in the SSA have improved knowledge about climate change risks and have adopted various adaptation strategies. The significance of adaptation in addressing the challenges posed by global climate change is widely recognised. However, it is important to acknowledge the socio-political dynamics and power struggles associated with the practice of adaptation (Eriksen et al. 2015). As a result, research studies such as those of Barnett and O'Neill (2010) and Johnson et al. (2023) have highlighted the need for careful planning to prevent maladaptation. Therefore, it is imperative to increase people's knowledge and perceptions of climate-related risks in order to develop effective strategies for adaptation (Ricart et al. 2023; Yaro 2013). Ricart et al. (2023) provided a review of climate change awareness, perceived impacts, and adaptation based on the experiences and behaviours of farmers. Within this context, the authors describe risk perception as the way people receive information or stimuli from their surroundings and subsequently convert them into psychological awareness, enabling them to take appropriate actions or reactions. Griffin et al. (2008) further explained risk perception as the integration of an individual's assessments regarding the likelihood of a hazard occurring, coupled with their perception of the potential severity of the ensuing outcomes. The variations in climate risk assessment within a community can be attributed to disparities in information, varying levels of uncertainty, distinct political structures, and divergent interests among individuals and groups (Glaus et al. 2020; Slovic 1987). The concept of risk perception has been recognised by several researchers as a fundamental catalyst for adaptive behaviour (Barbara et al. 2023; Ricart et al. 2023; Yaro 2013). However, Wiegel et al. (2021) contend that its incorporation into environmental research has been infrequent.

Several studies on the climate risk perceptions, knowledge, and adaptation strategies of smallholder farmers have been conducted in the SSA region. For instance, Chichongue et al. (2015) reported that farmers in Lichinga and Sussundenga districts, Mozambique, perceive increased temperatures and variable rainfall to have adversely affected maize cultivation in the area. As a result, the farmers have diversified their crops and cultivated drought-resistant crops as a way of adapting to or coping with climate change (Chichongue et al. 2015). According to Sutcliffe et al. (2016), farmers in rural Ngabu Town and Kasungu-Lilongwe Plain, Malawi, prefer to cultivate maize in the short season and believe that it is the best adaptation strategy to drought events. Regardless, the researchers found that the meteorological data for the locations showed contrary evidence for the short season and advised that the adaptation effort by the farmers may not be appropriate (Sutcliffe et al. 2016). Additionally, Ochieng et al. (2017) pointed out that a substantial number of farmers in rural Kenya believe in climate

change incidence, especially in the increasing and changing parameters of temperature and rainfall. The researchers assert that the farmers adapt by cultivating different crop varieties under the guidance of extension services (Ochieng et al. 2017). According to the researchers, age and access to extension services are the main factors that shape the farmers' perceptions of climate risks (Ochieng et al. 2017). In the Zou Department of Benin, the findings of Fadina and Barjolle (2018) showed that farmers have an increased perception of climate change, increasing temperatures and winds, and decreasing rainfall. According to the findings, farmers adapt by adopting strategies such as fertiliser and pesticide application, improving seed varieties, crop diversification, and livestock rearing, among others (Fadina and Barjolle 2018). The findings further demonstrated that the educational level and years of farming significantly influenced the farmers' adaptation decisions (Fadina and Barjolle 2018). Tesfahun and Chawla (2020) reported that most farmers in Ethiopia's Eferatena-Gidem district believed that temperature and rainfall had increased and decreased in the last two decades, respectively. The researchers further indicated that the farmers in the area have employed a range of adaptation strategies, including changing the planting dates of their crops, engaging in off-farm livelihood activities, and planting improved seed varieties, among others (Tesfahun and Chawla 2020). The findings of Amadou et al. (2022) showed that most farmers in the Béguéné village in central Mali believe that temperature and rainfall have increased and decreased, respectively. The researchers further stated that the farmers cultivate drought-resistant crops and water-saving measures as their adaptation strategy (Amadou et al. 2022). The findings of Amani et al. (2022) have once again revealed farmers' perceptions and adaptation strategies in the Bafuliru and Lega areas of the Itombwe Mountains in the eastern Democratic Republic of the Congo. According to the researchers, the farmers in the Bafuliru area reported more climate risks and have adopted numerous adaptation measures than in the Lega area (Amani et al. 2022). The researchers highlighted the diverse sociocultural contexts that exist in the area and suggested a better adaptation strategy (Amani et al. 2022). In Senegal, Zagre et al. (2024) found that farmers in the Meouane, Daga Birame, and Thiel regions have improved knowledge of climate risk indicators such as increasing temperatures and variable rainfall patterns. The researchers further indicated that various factors, including government subsidies, credit access, extension services, and farming experience, among others, influence farmers' adaptation choices (Zagre et al. 2024). The findings of Alhassan and Haruna (2024) also established that aside from possessing increased knowledge about climate risks, rural farmers' household income and land size shape their adaptation decisions to climate risks in Nigeria and Ethiopia. Local social networks and agricultural extension services heavily influence farmers' adaptation choices, according to the researchers (Alhassan and Haruna 2024).

Ghana is not exempt from the escalating effects of climate change and variability, and it has comparable vulnerabilities to other countries in the SSA region. The Ministry of Environment, Science, Technology, and Innovation (MESTI) in Ghana reported a temperature rise of about 1.0 °C from 1960 to 2006 and has projected a further increase ranging from 1.7 °C to 2.0 °C (MESTI 2013). The climate in Ghana has undergone significant changes and has become more variable (Asare-Nuamah and Botchway 2019). Therefore, this has posed considerable difficulties for agricultural practises and the livelihoods of smallholder farmers (Cudjoe et al. 2021). Considering the changing and variable nature of Ghana's climate and its related impacts on agriculture, it is imperative to acknowledge the significance of farmers' risk perceptions and knowledge, particularly among smallholder farmers, in order to effectively implement suitable adaptation strategies.

A number of studies have been undertaken to examine the risk perceptions, knowledge, and adaptation strategies of smallholder farmers in Ghana in relation to climate change and variability. For instance, Ntim-Amo et al. (2022) reported that farm households in the northern region of Ghana have a perception of severe floods, perceive a greater likelihood of flooding, experience a sense of worry, and face potential risks to their farm inputs and yields. According to Ntim-Amo et al. (2022), it was found that farmers in northern Ghana have a low rate of adoption of flood risk adaptation strategies. However, the researchers suggest that these farmers are inclined to adopt a greater number of strategies in order to effectively adapt to and mitigate flood risks. Using the climate variability perception index, Yiridomoh et al. (2021) found that women smallholder farmers in the Wa West district are vulnerable to drought, floods, and bush fires. The researchers further indicated that the smallholder farmers have engaged in multiple off-farm adaptation strategies such as petty business, poultry and livestock keeping, and agro-processing as a response to climate variability (Yiridomoh et al. 2021). In the Lawra and Nandom districts in the Upper West region, Lawson et al. (2020) highlighted that women smallholder farmers perceive rainfall to be increasing erratic and increased average temperatures. The adoption of adaptation strategies in these districts is influenced by socio-economic factors such as age, marital status, and residential status. Within farmer households, power dynamics and decision-making processes further shape these factors (Lawson et al. 2020). Similarly, Yamba et al. (2019) provided information indicating that smallholder farmers in the Bosomtwe district in the Ashanti region have reported a noticeable rise in temperature and erratic rainfall patterns. These observations corroborated the meteorological data collected in the area. According to Yamba et al. (2019), a majority of farmers hold the belief that deforestation plays

a substantial role in both climate change and variability. Additionally, using multinominal logit regression, Sadiq et al. (2019) reported that in the Yilo Krobo municipality and the Ayensuano district in the Eastern region of Ghana, smallholder farmers adoption of appropriate agricultural practises is influenced by their perceptions of rainfall, credit access, and farming experience, whereas their adoption of soil-related strategies is influenced by gender and rainfall perception. The researchers went on to state that smallholder farmers farming experience and rainfall perception influenced their adoption of improved variety strategies (Sadiq et al. 2019). The findings of Asravor (2018) revealed that the effects of the variations in crop yield, prices of fertiliser, and crop prices on household income were perceived as the greatest sources of risk by smallholder farmers in northern Ghana. According to Asravor (2018), the most effective risk management strategies of the farmers in northern Ghana include stabilising household income through the cultivation of different crops, storing feed and seed reserves, and spreading sales. Furthermore, the study conducted by Antwi-Agyei et al. (2017) revealed variations in the perception of climatic and non-climatic stressors among smallholder farmers in northern Ghana. Nevertheless, the researchers identified several predominant stressors that were consistently reported across different levels. These stressors encompassed a lack of money, the high cost of farm inputs, erratic rainfall, damage to crops by cattle, limited access to markets, and a lack of farming equipment. Moreover, Yaro (2013) highlights that small-scale farmers in Gomao-Akotsi and commercial farmers in Nsawam, Ghana, possess a comprehensive understanding of climate change patterns and their impact on agricultural productivity and other aspects of their livelihoods. According to Yaro (2013), the results indicate that commercial farmers exhibited a broader understanding of the scientific aspects of climate change, whereas small-scale farmers provided a localised explanation of observed climate changes. Also, Fosu-Mensah et al. (2012) reported that most smallholder farmers perceive increasing and decreasing temperatures and rainfall, respectively, in the Sekyedumase district in the Ashanti region. Using logit regression analysis, the researchers went ahead to indicate that access to extension services, credit, soil fertility, and land tenure are the essential factors influencing farmers' perception and adaptation in the district (Fosu-Mensah et al. 2012).

In Ghana, like other SSA countries (Akinyi et al. 2021; Gbegbelegbe et al. 2018), smallholder farmers employ various strategies to effectively adapt to the negative impacts of climate change and variability. The strategies encompass a range of activities such as livestock husbandry, the application of fertilisers, engaging in small-scale business ventures, cultivating drought-resistant crop varieties, utilising improved seed varieties, practising crop rotation, using irrigation systems, adopting mulching techniques, and engaging in non-farm activities, among other approaches (Asravor 2018; Sadiq et al. 2019; Yamba et al. 2019; Yaro 2013; Yiridomoh et al. 2021). Despite the implementation of various adaptation strategies by smallholder farmers in the country, they face several constraints, including financial limitations, pest and disease infestations, low market demands, high input costs, and inadequate extension services (Sadiq et al. 2019; Yiridomoh et al. 2021).

As previously noted, the aforementioned studies primarily focused on examining the climate risk perception and adaptation strategies of smallholder farmers' activities in the mid-to-northern half of Ghana. However, they overlooked the equally significant coastal Savannah agroecological zone. This zone warrants an investigation in order to gain a comprehensive understanding of climate-related challenges and adaptive measures among smallholder farmers. Conducting research on the climate risk perception and adaptation strategies of smallholder farmers in the coastal Savannah agroecological zone, an area where no research exists, is of utmost importance. This study holds significant importance for the region of Ghana as well as the broader global society, given the spatial, temporal, and socio-political dimensions of the phenomenon of global climate change. This study contributes to the growing body of literature about climate change risk perception and adaptation strategies, examining these issues across several spatial, temporal, socio-economic, and socio-political levels.

Methodology

Study area

The coastal Savannah agroecological zone is located within the central and eastern portions of Ghana's coast and encompasses three distinct administrative regions, namely the Central, Greater Accra, and Volta regions (Fig. 1). The climate of the zone and Ghana as a whole is characterised by a tropical environment that experiences distinct periods of dryness and rainfall (Addi et al. 2021). The intertropical discontinuity and the West African monsoon both play a significant role in shaping this climatic pattern in the zone (Addi et al. 2021).

Based on climatology, the zone is classified as a dry equatorial climate zone and is recognised as the driest in Ghana (Addi et al. 2021). The zone has a maximum and minimum mean annual temperature of 27.9 °C and 26.6 °C, respectively (Ankrah et al. 2023a; Baidu et al. 2017). Despite exhibiting a bimodal rainfall pattern, the zone is characterised by the lowest precipitation levels in the country (Baidu et al. 2017; Ghana Statistical Service [GSS] 2013).

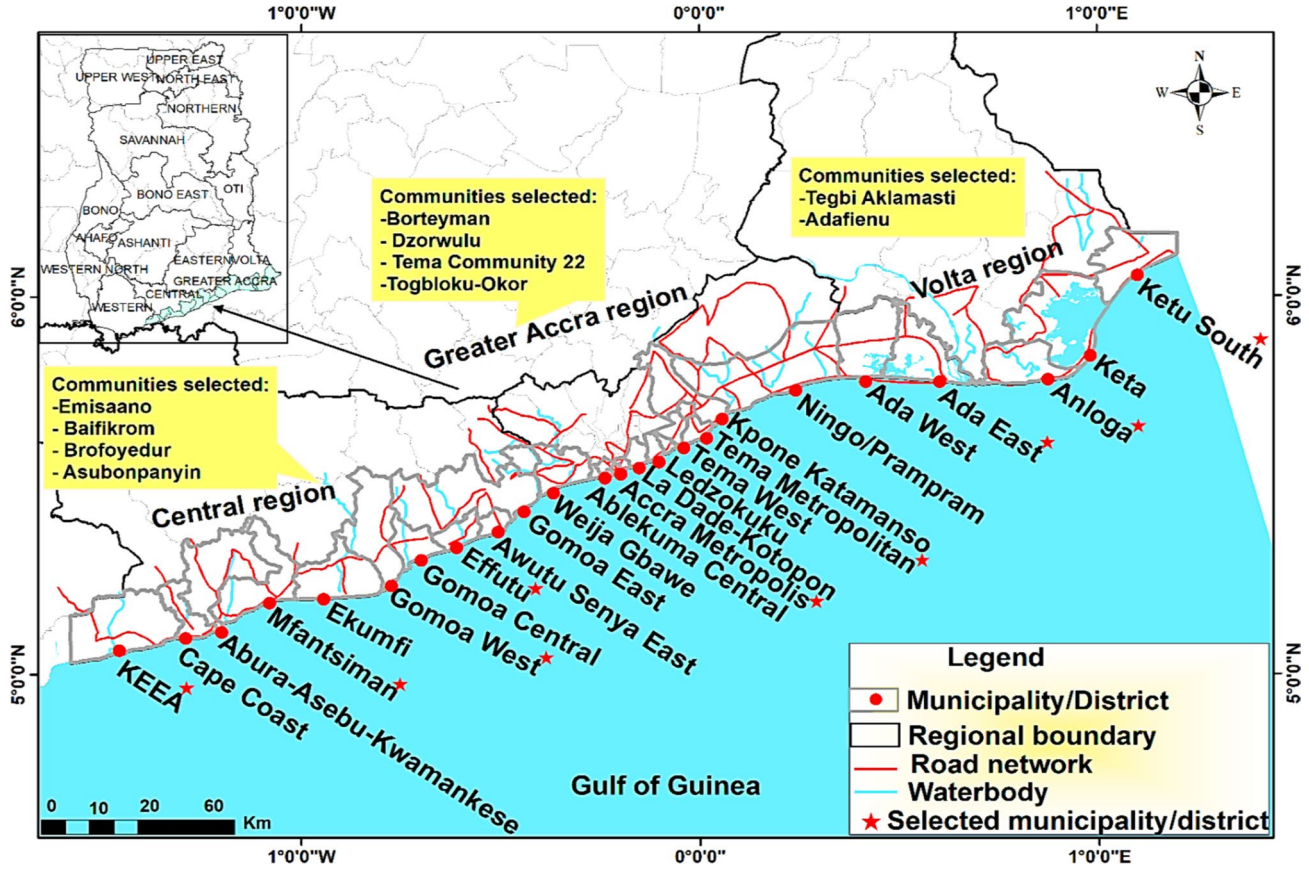

Fig. 1 Map showing the coastal Savannah agroecological zone and the selected municipalities and districts

According to Ankrah et al. (2023a), the range of average annual rainfall varies from a minimum of 978.4 mm to a maximum of 1339.9 mm. The major season of rainfall in the zone spans from April to July, while the minor season starts from September to early November. Subsequently, the dry season commences from late November to March (Dickson and Benneh 2001). The elevation of the zone varies from a minimum of − 3 m to a maximum of 641.2 m (Ankrah et al. 2023a). The terrain of the area is comprised of isolated hills, undulating plains, and lowland cliffs characterised by sandy beaches and marshes (GSS 2013).

The predominant vegetation in the zone consists primarily of grassland, with a few trees in the central portion and the presence of shrubs, thickets, and mangroves in the eastern section (GSS 2013). The coastal nature of the zone significantly contributes to Ghana's gross domestic product (GDP) (GSS 2013). Agriculture is widely recognised as a significant economic activity within the zone, owing to its favourable conditions for cultivating various crops, including maize, cassava, cocoyam, plantains, and vegetables, among others (Addi et al. 2021; GSS 2013; Yaro 2013).

Several factors led to the decision to study the coastal Savannah agroecological zone. Despite having two distinct rainfall seasons, the coastal Savannah agroecological zone receives the least amount of rainfall when compared to the other five agroecological zones in the country (Addi et al. 2021). The area's coastal position increases its susceptibility to impacts caused by land and ocean interactions (Addi et al. 2021). The findings of Addi et al. (2021) and the Ghana Statistical Service (GSS) (2013) confirm that agriculture plays a significant role in the economic activities within the coastal Savannah agroecological zone.

Description of data sources and collection procedure

The study used a combination of data sources: qualitative and quantitative data (mixed-methods approach) (Creswell 2014; Tashakkori and Creswell 2007) to gain insight into smallholder farmers' perceptions of climate risks and adaptation strategies in the coastal Savannah agroecological zone of Ghana. The study used data from both primary and secondary sources. Primary data were acquired through a semi-structured questionnaire survey and interviews. The Ghana Meteorological Agency (GMet) provided the secondary data, which included climatological records of maximum

and minimum temperature, rainfall, and wind speed from 1981 to 2021. The use of this period was necessitated by the presence of more gaps in the years preceding 1981. In other words, this study did not include the years before 1981 because they had a percentage of missing values greater than 5%. The data was collected from eleven synoptic stations of the GMet for various locations, such as Elmina, Cape Coast, Saltpond, Apam, Winneba, Accra, Tema, Ada Foah, Anloga, Keta, and Denu. In each dataset, the percentage of missing values was less than 2%. In accordance with the recommendation put forth by Monteiro et al. (2018), the National Aeronautics and Space Administration/Prediction of Worldwide Energy Resources (NASA/POWER) (https://power.larc.nasa.gov/) satellite data were employed for the purpose of addressing these data deficiencies.

The semi-structured questionnaire survey consisted of four different sections: socio-demographic characteristics, perceived knowledge and causes of climate change and variability, perceived climate risks to farming activities, and adaptation strategies. The survey instrument comprised a combination of closed-ended and open-ended questions. Typically, the completion of a questionnaire requires approximately 20 to 30 min of a respondent's time. Six field assistants were provided with training on the questionnaire, the use of the KoboToolbox software (https://www.kobotoolbox.org/), and ethical considerations pertaining to data collection. The selection of field assistants was characterised by diversity, as individuals proficient in distinct languages such as Fante, Ga-Dangme, and Ewe were chosen to work in the eight selected communities. The survey was conducted among respondents using mobile devices through the KoboToolbox platform from February to April 2023.

In order to qualify as a key informant for the interview, several criteria must be met. First of all, the individual must be a native of the farming community under study. Additionally, they must have lived in this community for at least 40 years. Lastly, their livelihood must be exclusively dependent on farming. The farmers who were considered key informants were also smallholder farmers. After receiving recommendations from at least five respondents who completed the questionnaire in each community, the researcher proceeded to engage with these farmers, who served as key informants. Following the administration of the questionnaire survey, the field assistants proceeded to informally engage the respondents in identifying a specific farmer within the community whom they perceive as their 'leader' and who possesses a longer history in farming (including themselves if they believe they are the one). Leader here means the person has been farming for at least forty years and is a native of their community. The researcher compiled these farmers' names for each community, identified the most frequently mentioned by the respondents, and scheduled an interview with them. The respondents for the questionnaire administration were distinguished from those for the interview based on two factors: the number of years lived and being a native of the community. The interview primarily addressed inquiries pertaining to the strategies employed for adaptation and the barriers hindering the adoption of such strategies.

Nielsen and D'haen (2014) emphasised the significance of the participants' perceptions provided to the researchers during the data collection process. Nielsen and D'haen (2014) further underlined the importance of researchers' awareness, as these perspectives can either hinder or aid the process of collecting data. Hay (2010) emphasised the importance of thoughtful reflection, when researchers recognise their social positions and carefully assess their positionality, social interactions, and their possible effect on data collection and interpretation of findings. Throughout the interview process in the present study, the researcher recognised the concept of positionality and its possible effect on data collection. Consequently, the researcher endeavoured to reduce any possible prejudices. Because the selection of the eight study communities did not include the community the researcher belongs to in the coastal Savannah zone, the researcher adopted an outsider (Holmes 2020; Richa and Geiger 2007). The participants identified the researcher as an insider based on the researcher's proficiency in speaking native languages (Holmes 2020; Richa and Geiger 2007). As a result, the researcher gained trust, which led the participants to be more truthful and elaborate in sharing their experiences regarding their adaptation strategies and the barriers that limit their adoption of such strategies. The participant perceived the researcher as harmless, which encouraged the researcher to ask more detailed questions and even extend invitations to visit their farms. Some participants felt that the researcher's high level of education made him appear very informed about the interview topics. As a result, they would occasionally seek confirmation from the researcher based on their own answers. The researcher perceived this as a concern and resolved it by instilling confidence in the participants. The researcher achieved this by acknowledging the participants' knowledge as long-standing farmers with decades of experience. The researcher emphasised their role in gathering valuable insights to inform more effective policies. The researcher's insider position did not have a negative effect on the qualitative findings. Instead, it facilitated the generation of more detailed and in-depth shared knowledge and experiences from the participants, specifically addressing their farming adaptation strategies and the barriers that limit their adaptation decisions. In the process of transcribing the interview, the researcher, although regarded as an insider, maintained objectivity, cultural neutrality, and impartiality towards the prejudices of the participants (Holmes 2020; Kusow 2003).

Prior to commencing the interview, the participant was provided with a consent form that outlined their rights as a participant, such as the voluntary nature of the interview and their prerogative to withdraw from the study or request the removal or deletion of their previously recorded responses. Anonymity and confidentiality were ensured for the participant through the omission of personal identifying information, such as their name. The abbreviations D1, D2, D3, D4, D5, D6, D7, and D8 were used to represent the participant names, which were then followed by their respective communities. For example, the abbreviations D1: Emisano, D2: Baifikrom, D3: Brofoyedur, D4: Osobonpanyin, D5: Borteyman, D6: Togbloku Okor, D7: Tegbi Aklamatsi, and D8: Adafienu represent the participants in the communities of Emisano, Baifikrom, Brofoyedur, and Osobonpanyin, Borteyman, Togbloku Okor, Tegbi Aklamatsi, and Adafienu, respectively. The commencement of the interview was contingent upon the participant's explicit agreement and subsequent execution of the consent form. The interview took place in a setting where the participant was actively involved, specifically within the confines of their own home, which gave them a sense of freedom and privacy. The interview was carried out using the languages that were familiar to the leaders, such as Fante, Ga-Dangme, Ewe, and Twi. The interviews were recorded solely upon the agreement of both the interviewer and the participant. Furthermore, detailed notes were taken, leading to a total of 200 h spent, during which each of the eight key informants was interviewed for a duration of 25 min. The responses of the participants were transcribed verbatim, capturing their exact words. The quotations provided in this study reflect the individual viewpoints of the participants, which were collected through interviews conducted from February to April of 2023.

The study focused on two main research objectives: identifying smallholder farmers' adaptation strategies and understanding the barriers that limit their adoption of these strategies. These objectives guided the analysis of interviews conducted with eight key informants. Subsequently, the study utilised an engaging and inductive qualitative approach to analyse the data and directly generate themes (Arku et al. 2012; Strauss and Corbin 1990). The interviews were transcribed from the local languages of the key informants into English. This was done thoroughly by carefully reading the interview notes and continuously playing back the recorded audio to guarantee the accuracy and reliability of the findings (Arku et al. 2012; Krefting 1991). The interview transcripts were categorised into themes according to the participants' strategies for adaptation, barriers that limit their adoption of these strategies, and additional factors that encourage or hinder adaptation. The interview transcripts were coded and analysed using the trial version 24.0 of ATLAS.ti software, available at https://atlasti.com/free-trial-version. This analysis enabled the identification of the variations, similarities, and associations in the adaptation strategies and barriers faced by the farmers (key informants). The graphical representation of a network of themes was accompanied by direct quotations, serving to offer the necessary context for the farmers' viewpoints.

Sampling procedure

A multi-stage sampling technique was used to collect primary data from the respondents. Saunders et al. (2012) assert that the use of the multi-stage sampling technique is advantageous in addressing the issue of face-to-face interaction with a sample that is geographically spread out. The coastal Savannah agroecological zone was purposefully selected in the first stage due to its lower rainfall amounts compared to the other five agroecological zones as well as its higher frequency of drought and wetness events, which negatively affect agricultural activities (Addi et al. 2021; Ankrah et al. 2023a). In the second stage, the simple random sampling technique was employed to select eight districts or municipalities (Table 1) across the zone. Additionally, one community was randomly selected from each of the municipalities or districts, resulting in a total of eight communities (Table 1). Due to the urbanised nature of the Greater Accra region, the present study deemed it necessary to treat the Ashaiman, Kpone-Katamanso, and Ayawaso West municipalities as a single community. This decision was made in response to the challenges encountered in accurately identifying farmers within these areas.

The third stage involved a random selection of 100 smallholder farmers each from the eight communities, for a total of 800 farmers. The random selection of 100 smallholder farmers from each of the eight communities ensured a fair representation of the farmers, as community-specific data

Table 1 Communities and districts/municipalities selected for the study

Community	District/Municipality	Region
Asubonpanyin	Effutu	Central
Brofoyedur	Gomoa West	Central
Emisaano	Komenda/Edina/Eguago/Abirem	Central
Baifikrom	Mfantsiman	Central
Tema Community 22	Ashaiman[a]	Greater Accra
Borteyman	Kpone-Katamanso[a]	Greater Accra
Dzorwulu	Ayawaso West[a]	Greater Accra
Togbloku-Okor	Ada East	Greater Accra
Adafienu	Ketu South	Volta
Tegbi Aklamasti	Anloga district	Volta

[a]Treated as a single community

regarding the number of farmers at the municipal or district level of the respective communities were unavailable. In the last stage, a purposeful decision was made to interview eight smallholder farmers who were recognised as key informants. One participant was selected from each of the communities in question.

Data analysis and statistical measures

The data obtained from the questionnaire survey was exported in Excel format and subsequently imported into the Statistical Package for the Social Sciences (SPSS) software (version 26.0) for the purpose of analysis. As a result, an appropriate statistical analysis was conducted. The independent variables in this study encompassed the socio-demographic characteristics of the smallholder farmers, including age, gender, level of education, and years of farming. These variables were chosen based on their theoretical positive influence on climate risk perception and adaptation strategies (Fosu-Mensah et al. 2012). For instance, researchers have suggested that the gender of farmers can impact their perceptions of climate risks and the strategies they use to adapt to them (Fosu-Mensah et al. 2012; Phiri et al. 2004). Research has shown that there is a positive association between the level of education and the adoption of modern technology among farming households (Deressa et al. 2009; Fosu-Mensah et al. 2012). Fosu-Mensah et al. (2012) and Nhemachena and Hassan (2007) argued that more farming experience enhances farmers' odds of adopting adaptive strategies. According to the researchers, farmers gain expertise and knowledge about the climate and make informed decisions about the most suitable crops and planting methods (Fosu-Mensah et al. 2012; Nhemachena and Hassan 2007). The study focused on the aforementioned variables, but it is worth noting that other factors, such as farm size, income, credit access, access to extension services, household size, social networks (members of associations), information, and social status, have also been identified as influencing farmers' perceptions and adaptation strategies (Ado et al. 2020; Bagambilana and Rugumamu 2023; Dasmani et al. 2020; Jairo and Korir 2019). The binary logistic regression analysis was employed to assess the effect of the independent variables on the adoption of adaptation strategies by farmers. The choice to use binary logistic regression in this study was influenced by its extensive use in previous research on farmers' perceptions of climate risks and adaptation strategies. Notable studies that have employed this method include Abid et al. (2015), Ado et al. (2020), Bagambilana and Rugumamu (2023), Batungwanayo et al. (2023), Fosu-Mensah et al. (2012), Sertse et al. (2021), Shah et al. (2023), and Tesfahun and Chawla (2020). This study assessed farmers' adoption of particular adaptation strategies based on five variables: cultivating different types of crops, fertiliser application, planting improved varieties of seed, rearing livestock, and the use of irrigation. Each of these five dependent variables was measured on a dichotomous scale and represented as 1 (if a farmer adopted a particular adaptation strategy) and 0 (if a farmer did not adopt a particular adaptation strategy). Previous studies, including those of Ado et al. (2020), Bagambilana and Rugumamu (2023), Batungwanayo et al. (2023), Dasmani et al. (2020), Shah et al. (2023), and Yaro (2013), informed the choice of these variables. The statistical procedures mentioned above were chosen because the variables involved are categorical and dichotomous. The aim was to assess the predictive capacity of these variables in determining the odds of farmers' adoption of particular adaptation strategies. The ordinary Kriging interpolation technique was employed to understand the spatial distribution of annual variations in the climate variables. The linear regression test was again used to represent the trends in the climate variables across the zone, as used earlier by Jaiswal et al. (2015).

Ethical considerations

The study started after adhering to the research ethics protocol and obtaining approval from the ethics commission of the Faculty of Arts and Humanities at the University of Porto. The research, including the instruments used for data collection, went through an ethical review procedure to ensure compliance with ethical standards and to eliminate any potential risks or disadvantages for the participants. The approval was granted through the adoption of Resolution No. 31/CEFLUP/.

Results

Socio-demographic characteristics of respondents

Table 2 shows the socio-demographic characteristics of the 800 respondents who participated in the study. The majority of respondents (48%) were within the age range of 41 to 50 years, while the lowest number (58, or 7%) were above the age of 50. The survey indicated a higher participation rate among males (78%) in comparison to females (22%). A substantial number (790, or 99%) of the respondents were in a marital relationship, with just a few (10, or 1%) identified as widows. The majority of the respondents (49%) had only received a primary education, while 31% had no formal education, according to their educational level, with the lowest number (4%) having completed senior secondary or high school. The majority of the respondents, specifically 43%, reported having a household size of 4, followed by 27% who reported having a household size greater than 5. Conversely, the lowest proportions of respondents, each accounting for

Table 2 Socio-demographic characteristics of respondents

Variable	Category	Frequency	Percentage (%)
Age	20 – 30	0	0
	30 – 40	361	45
	41 – 50	381	48
	> 50	58	7
Gender	Female	179	22
	Male	621	78
Marital status	Married	790	99
	Widow(er)	10	1
Educational level	Junior Secondary/high School	129	16
	Senior secondary/high school	33	4
	No formal education	245	31
	Primary	393	49
Household size	3	121	15
	4	343	43
	5	121	15
	> 5	215	27
Native of a community	Yes	800	100
	No	0	0
Years of farming	< 20	380	47
	20 – 30	344	43
	> 30	76	10

Source: (Field survey, 2023)

15%, reported having household sizes of 3 and 5. All of the respondents (100%) indicated that they were native to their respective communities. A substantial majority of the respondents (47%) reported having engaged in farming for a time frame of less than 20 years, followed by 43% between 20 and 30 years, and the least (10%) for more than 30 years.

Online Resource 1 displays the socio-demographic characteristics of each community, highlighting the variations between them. The majority of respondents (77%) in the Dzorwulu-Borteyman-Tema Community 22 community were between the ages of 31 and 40. The Togloku-Okor community came in second with 74% in the same age groups, while Tegbi Aklamatsi had the lowest percentage (0%) among those over 50. None (0%) of respondents in the communities were between the ages of 20 and 30 (Online Resource 1). Their gender distribution ranged from 93% for males in the Togloku-Okor community to 7% for females (Online Resource 1). All (100%) of the respondents in the communities of Emisano, Brofoyedur, Dzorwulu-Borteyman-Tema Community 22, and Togloku-Okor were married. Only a few of them were widows, mostly in Baifikrom (1%), Osobonpanyin (3%), Tegbi Aklamatsi (2%), and Adafienu (4%). Their level of education ranged from a high of 59% in the Togloku-Okor community for primary education to 0% in the Emisano and Baifikrom communities for senior secondary or high school. None (0%) of the respondents in the study communities had completed tertiary education at the time of the survey (Online Resource 1). Respondents in the Tegbi Aklamatsi community had the largest (53%) household size of four, while the Emisano community had the smallest (3%) household size of three (Online Resource 1). All of the respondents (100%) were native to their community. The majority (64%) of respondents in Dzorwulu-Borteyman-Tema Community 22 had less than 20 years of farming experience, while the lowest (7%) were in the communities of Dzorwulu-Borteyman-Tema Community 22 and Togloku-Okor with more than 30 years of farming experience.

Perceived knowledge and causes of climate change and variability

Table 3 shows the respondents perceived knowledge and causes of climate change and variability. According to Table 3, all of the respondents (800, or 100%) indicated their awareness of climate change and variability. The majority of respondents (662, or 83%) mentioned that television serves as the primary medium through which they obtain information regarding climate change and variability. A substantial portion of respondents (316, or 40%) attributed climate change and variability primarily to negative human actions. Subsequently, a proportion of 284 or 35% was observed for both negative human actions and natural events, while the lowest percentage of 24 or 3% was attributed to God's

Table 3 Perceived knowledge and causes of climate change

Variable	Category	Frequency	Percentage (%)
Awareness about climate change	1. Yes	800	100
	2. No	0	0
Sources of information about climate change	1. Radio	138	17
	2. Television	662	83
Causes of climate change	1. Both negative human actions and natural events	284	35
	2. Natural events	176	22
	3. Negative human actions	316	40
	4. Punishment from God	24	3
Factors contributing to climate change	1. A natural event	189	24
	2. Bush burning	0	0
	3. Deforestation	611	76
	4. Urbanization	0	0
	5. Vehicular fumes/carbon monoxide	0	0
Temperature over the last two decades	1. Increased	800	100
	2. Decreased	0	0
	3. No change	0	0
	4. Don't know	0	0
Dry season temperature over the last two decades	1. Increased	800	100
	2. Decreased	0	0
	3. No change	0	0
	4. Don't know	0	0
Rainy season temperature over the last two decades	1. Increased	762	95
	2. Decreased	0	0
	3. No change	38	5
	4. Don't know	0	0
Length of the hot periods over the last two decades	1. Increased	800	100
	2. Decreased	0	0
	3. No change	0	0
	4. Don't know	0	0
Length of the cold periods over the last two decades	1. Increased	0	0
	2. Decreased	757	95
	3. No change	19	2
	4. Don't know	24	3
Rainfall changes over the last two decades	1. Increased	285	36
	2. Decreased	515	64
	3. No change	0	0
	4. Don't know	0	0
Wet season rainfall over the last two decades	1. Increased	473	59
	2. Decreased	326	41
	3. No change	1	0
	4. Don't know	0	0
Dry season rainfall over the last two decades	1. Increased	8	1
	2. Decreased	761	95
	3. No change	31	4
	4. Don't know	0	0
Intensity of rainfall events over the last two decades	1. Increased	632	79
	2. Decreased	168	21
	3. No change	0	0
	4. Don't know	0	0

Table 3 (continued)

Variable	Category	Frequency	Percentage (%)
Wind over the last two decades	1. Increased	800	100
	2. Decreased	0	0
	3. No change	0	0
	4. Don't know	0	0
Intensity of dry season wind over the last two decades	1. Increased	800	100
	2. Decreased	0	0
	3. No change	0	0
	4. Don't know	0	0
Intensity of wet season wind over the last two decades	1. Increased	694	89
	2. Decreased	106	13
	3. No change	0	0
	4. Don't know	0	0
Gendered dimension of accessing information in farmers' awareness and understanding of climate change			
Sources of information about climate change			
-Television	1. Males (females)	540 (122)	87 (68)
-Radio	2. Males (females)	81 (57)	13 (32)
Causes of climate change			
-Both negative human actions and natural events	1. Males (females)	233 (51)	37 (28)
-Natural events	2. Males (females)	104 (72)	17 (40)
-Negative human actions	3. Males (females)	277 (39)	45 (22)
Punishment from God	4. Males (females)	7 (17)	1 (10)
Factors contributing to climate change			
-A natural event	1. Males (females)	107 (82)	17 (46)
-Deforestation	2. Males (females)	514 (97)	83 (4)

Source: (Field survey, 2023)

punishment. The respondents identified deforestation (611, or 76%) and natural events (189, or 24%) as the primary factors responsible for climate change and variability. The respondents in the study were unable to identify the significant impact of urbanisation and vehicular emissions.

In terms of gender dimensions, both males and females appeared to use television more than radio when accessing information about climate change awareness and understanding. However, more males (540, or 87%) used television than females (122, or 68%). The causes of climate change vary according to gender. A substantial number (277, or 45%) of males assigned the reasons for climate change to negative human actions, whereas 72, or 40%, of females attributed it to natural events. Both male and female respondents attributed deforestation to causing climate change and variability. Nonetheless, response rates varied from 514 (83%) for men to 97 (54%) for women (Table 3).

All of the respondents (800, or 100%) indicated that temperatures and particularly dry season temperatures in their respective communities observed an increase over the past two decades. A significant percentage (762, or 95%) of respondents reported that there has been an increase in temperatures during the rainy season over the past two decades. However, a small minority (38, or 5%) perceived no change in temperatures during this period. In addition, all of the respondents (800, or 100%) stated that the length of hot periods in their respective communities has shown an increase over the course of the past two decades. Furthermore, a significant majority (757, or 95%) of the respondents reported a decrease in the length of cold periods during the same time frame. The majority of the respondents (515, or 64%) reported a decrease in total rainfall over the past two decades, whereas 285 or 36% observed the opposite trend. Notwithstanding, most of them (473, or 59%) reported an increase in the wet season rainfall over the last two decades, and the opposite of 761 or 95% was true for the dry season rainfall. A large proportion of the respondents (632, or 79%) reported an increase in the intensity of rainfall events in their respective communities over the past two decades, with only 168 or 21% indicating a decrease. All of the respondents (800, or 100%) claimed that overall wind speed, particularly the intensity of the wind during the dry season, has exhibited an increase over the past two decades. The vast majority (694, or 87%) of respondents similarly reported

the same pattern for the wet season wind in their respective communities.

Online Resource 2 presents the differences in perceived knowledge and causes of climate change, as well as the variability of the individual study communities. All respondents (100%) from the individual communities were aware of climate change and variability (Online Resource 2). The highest number of respondents (94%) in Dzorwulu-Borteyman-Tema community 22 identified television as their source of climate change information, while the lowest number (6%) identified radio as their source of information. None of the respondents mentioned newspapers as a source of climate change information (Online Resource 2). The respondents' attribution of the causes of climate change varied from a high of 63% for negative human actions in the community of Dzorwulu-Borteyman-Tema community 22 to a low of 0% for punishment from God in Dzorwulu-Borteyman-Tema community 22, Togbloku Okor, Tegbi Aklamatsi, and Adafienu (Online Resource 2). The Togbloku Okor community received the most (98%) responses on the factors contributing to climate change and variability when compared to the other communities (Online Resource 2). There were no variations in respondents' perceptions of temperature change, dry season temperature, rainy season temperature, and the length of hot periods over the last two decades, as all respondents (100%) reported an increase in the aforementioned variables (Online Resource 2). The majority (100%) of respondents in Baifikrom, Brofoyedur, Dzorwulu-Borteyman-Tema community 22, Togbloku Okor, and Adafienu reported that the length of cold periods had decreased over the last two decades, while the lowest (8%) in the community of Osobonpanyin reported no change. None of the respondents (0%) reported an increase in the aforementioned issue (Online Resource 2). Over the last two decades, the response rate to rainfall change ranged from 100% in Osobonpanyin, indicating a decrease, to 18% in Brofoyedur, indicating an increase. The responses to the wet season rainfall ranged from a high of 78% in Togbloku Okor, who indicated an increase, to a low of 1% in Tegbi Aklamatsi, who observed no change (Online Resource 2). The majority (100%) of respondents in Baifikrom, Brofoyedur, Dzorwulu-Borteyman-Tema community 22, Togbloku Okor, and Adafienu mentioned that dry season rainfall had decreased over the last two decades, while the lowest (8%) in Osobonpanyin reported both an increase and no change (Online Resource 2). Respondents in the Emisano community recorded the highest (97%) response rate to increased intensity of rainfall events over the last two decades, while the lowest (3%) emerged in that same community as a decrease. Over the last two decades, there has been no variation in responses to wind change or the intensity of dry season wind, with all (100%) respondents indicating an increase. On the other hand, responses to wet season wind changes varied from a high of 95% in Emisano and Togbloku Okor communities to a low of 5% in the same communities (Online Resource 2).

Perception of climate risks for farming activities

The respondents perceived climate risks for farming activities (Table 4). All of the respondents (100%) reported that their farming activities are susceptible to risks caused by climate change and variability. The respondents expressed diverse viewpoints regarding the climate-related risks that affect their farming activities. All of the respondents (100%) unanimously identified extreme temperatures as the primary climate risk that impacts their farming activities. This was followed by 99% for both drought and pest and disease risk on crops, with the lowest being 4% for erosion or soil fertility. The majority of the respondents (43%) identified the ripening of unmature crops as the primary effect of temperature changes, while 36% mentioned the drying of crops or seedlings. According to the majority of respondents (46%), a decrease in yield or harvest was the main impact of changes in rainfall on farming activities. Conversely, poor crop growth was deemed the least significant effect, with only 12% of respondents considering it as such. All of the respondents (100%) acknowledged that wind speed has significant implications for farming activities, particularly in terms of crop destruction and losses. The respondents also identified low productivity (53%) and losses (34%) as the primary effects of extreme events on farming activities. A significant proportion of the respondents (75%) identified poverty as the main effect of climate risks on their farming activities, while 23% stated food insecurity as the additional impact.

Online Resource 3 depicts the variations in respondents' perceptions of climate risks for farming activities in the various study communities. All respondents (100%) in their respective communities stated that climate change poses a risk to their farming activities (Online Resource 3). Extreme temperature was unanimously identified as the most impactful climate risk across all communities, with respondents in the individual study communities having varying perceptions of other climate risks affecting their farming activities (Online Resource 3). Respondents from the study communities had varying perspectives on the major effects of temperature on farming activities. However, the Brofoyedur community had the largest (63%) response rate to the ripening of unmatured crops, while the Osobonpanyin community had the lowest (8%) response rate, believing that temperature changes were less relevant than rainfall (Online Resource 3). Responses to the major effects of rainfall changes varied substantially throughout the study communities. Regardless, the majority (60%) of responses were about seedlings that failed to germinate in Dzorwulu-Borteyman-Tema Community 22, while the least (8%) were about poor crop growth

Table 4 Perception of climate risks for farming activities

Variable	Category	Frequency	Percentage (%)
Climate change poses risk to farming activities	1. Yes	800	100
	2. No	0	0
Climate risks that affect farming activities[a]	1. Drought	791	99
	2. Flood	83	10
	3. Pest and diseases on crops	792	99
	4. Heavy storms	519	65
	5. Livestock diseases	359	45
	6. Erosion/soil fertility	32	4
	7. Heat waves	219	27
	8. Delayed onset of rainfall	187	23
	9. Early cessation of rainfall	443	55
	10. Extreme temperature	800	100
Major effects of temperature on farming activities	1. Poor yields	157	20
	2. Ripening of unmatured crops	343	43
	3. Drying of crops/seedlings	292	36
	4. Not important as rainfall	8	1
Major effects of rainfall on farming activities	1. Lower yields/harvest	369	46
	2. Poor crop growth	92	12
	3. Seedlings unable to germinate	339	42
Major effects of wind on farming activities	1. Crop destruction and losses	800	100
Major effects of extreme events on farming activities	1. Crop destruction	105	13
	2. Losses	273	34
	3. Low productivity	422	53
Overall impact of climate variability and change	1. Food insecurity	184	23
	2. Low income	8	1
	3. Poverty	600	75
	4. Pest and diseases, rots and damages	8	1

[a]The participants had the option to select all the variable categories that were applicable to their case. As a result, each variable category had an expected frequency between 0 and 800, as well as up to 100%. Source: (Field survey, 2023)

in the Emisano community (Online Resource 3). There was no difference in responses to the major effect of wind on farming activities, as all respondents (100%) in the study community reported crop destruction and losses (Online Resource 3). The major effects of extreme events on farming activities varied greatly. The majority (68%) of the Tegbi Aklamatsi community reported low production, while only 10% of the Emisano community reported crop destruction. Climate change has a wide-ranging impact, with 91% indicating poverty in the Emisano community and 8% indicating low income, pests, diseases, rots, and damages in the Osobonpanyin community (Online Resource 3).

Spatial distribution of annual variations and trends in climate variables

Figures 2a–d illustrate the spatial variations of average annual rainfall, maximum and minimum temperatures, and wind speed, while Figs. 2e–g present the trends observed in the aforementioned climatic variables, excluding wind speed, across the zone. Figure 2a shows variability in rainfall across the zone. Notably, rainfall increased from the Central region to the Volta region, with an average annual amount ranging from a high of 1339.9 mm to a low of 978.4 mm between 1981 and 2021 (see Fig. 1 to understand the regional divisions). Thus, the communities located in the Central region experience a greater amount of annual rainfall in comparison to those in the Greater Accra and Volta regions. Figure 2b shows a contrasting pattern in the mean annual maximum temperatures. Here, mean annual maximum temperatures decrease from the Central region to the Volta region, with a range of 29.4 °C to 31.8 °C (Fig. 2b). The zone exhibits variations in mean annual minimum temperatures, ranging from 22.6 °C to 24.1 °C (Fig. 2c). Mean annual minimum temperatures appeared to be higher in some areas of the Greater Accra and Volta regions in comparison to those in the Central (Fig. 2c) (see Fig. 1 to understand the regional divisions). In general, wind speed

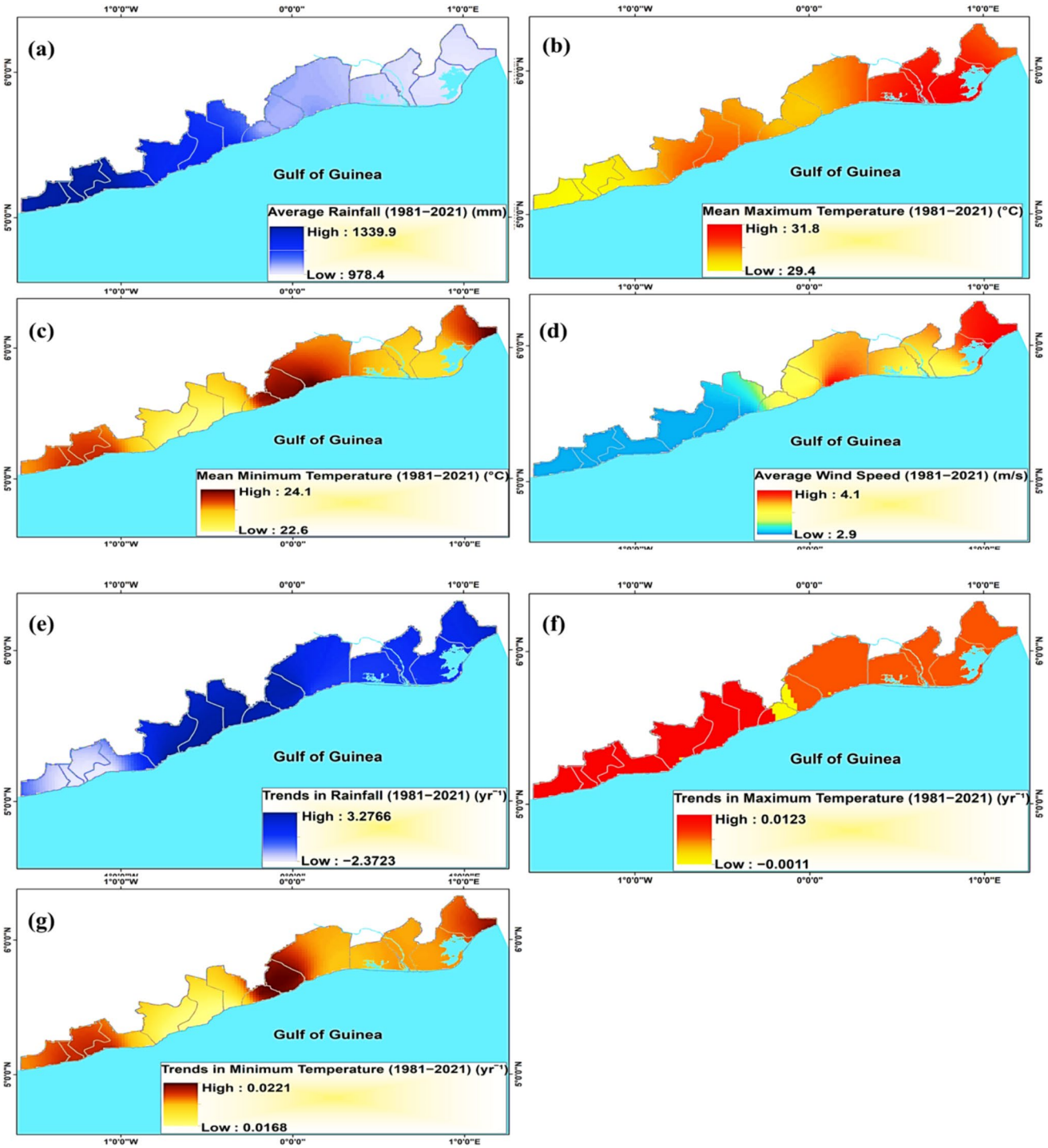

Fig. 2 Spatial variations of average annual rainfall (**a**), maximum (**b**), and minimum (**c**) temperatures, wind speed (**d**), and trends in average annual rainfall (**e**), maximum (**f**), and minimum (**g**) temperatures from 1981 to 2021

increases from the Volta region to the Central region, with an annual average range of 2.9 m/s to 4.1 m/s (Fig. 2d). The Greater Accra and Volta regions showed positive but weak rainfall trends, while the Central region exhibited a combination of positive and negative trends (Fig. 2e). The Central and Volta regions exhibited positive but weak trends in the mean annual maximum temperature, whereas the Greater Accra region displayed both positive and negative trends (Fig. 2f). The annual minimum temperature mean showed positive but weak trends across the zone (Fig. 2g).

Adaptation strategies to mitigate climate risks

Table 5 shows the adaptation or coping strategies utilised by the respondents in order to effectively manage the risks associated with climate change and variability in their farming activities. According to Table 5, 46% of the respondents employ the strategy of cultivating different crops on a single piece of land to adapt to or cope with the risks associated with climate change and variability. Subsequently, 18% of the respondents opted to employ the strategy of utilising improved seed varieties for planting, while only 1% resorted to using their family members as a means of labour in order to minimise costs. The main obstacles impeding the respondents' adoption of adaptation or coping strategies were financial constraints, accounting for 48% of the identified barriers, and the high prices of farm inputs or fertilisers, which constituted 32% of the barriers. The respondents identified the high prices of livestock feed as the least notable constraint, with only 2%.

Online Resource 4 depicts the variations in respondents' adaptation strategies as well as the barriers that limit their adaptation strategies in the study communities. Respondents in the various study communities use a variety of adaptation strategies, as presented in Online Resource 4. The Baifikrom community received the most (57%) responses for cultivating different types of crops, while the Osobonpanyin community received the fewest (4%) responses for using family labour (Online Resource 4). The major barriers to respondents' adoption of adaptive techniques differ substantially across study communities. A substantial number (65%) mentioned financial constraints in the Brofoyedur community, while just 4% reported poor extension services in the Baifikrom community (Online Resource 4).

Themes and constructs based on qualitative data

Participants' adaptation strategies

Figure 3 shows the graphical representation of the themes and constructs an analysis of the participants' adaptation strategies based on interview data derived from the eight farmers who were considered key informants of the study. Online Resource 5 displays a report on the farmers' adaptation strategies, the barriers that limit their strategies, and other factors that aid or hinder adaptation. According to Fig. 3, various themes were identified in the participants' adaptation strategies. These themes ranged from a high network of crop diversification to a low network of monocropping and support from microfinance groups. The networks (in blue dotted lines) show similarities in the adaptation strategies employed by the participants in the various communities. It appeared that participants in the communities of Emisano Togbloku Okor, Adafienu, and Osobonpanyin diversified their crops. The participants are of the view that it is always better to cultivate different types of crops, as they believe that when one crop dies or does not grow well, maybe the other can support it. For example, one participant shared their experience using crop diversification as an adaptation measure and noted: "I grow different types of vegetables like green pepper, cucumber, onion, cabbage, and maize. The maize is on different land." Another participant stated that he cultivates lettuce and cauliflower, which take a few months to harvest, and then cultivates cabbage, cumcumber, okro, or green pepper. A participant who cultivates similar crops three times a year also expressed that:

> It takes three months for the green pepper to mature. I cultivate green peppers three times a year, as well

Table 5 Adaptation strategies and barriers to mitigate climate risks

Variable	Category	Frequency	Percentage (%)
Adaptation strategies	1. Cultivate different types of crops	371	46
	2. Fertilizer application	120	15
	3. Use of family labour	4	0
	4. Plant improved variety of seeds	142	18
	5. Plant drought resistant crops	8	1
	6. Rearing of livestock	47	6
	7. Use irrigation	108	14
Major barriers that limit the adoption of the adaptation strategies	1. Financial constraints	386	48
	2. High prices of farm inputs/fertilizers	255	32
	3. Inadequate government support	62	8
	4. Poor extension services	79	10
	5. High prices of livestock feed	18	2

Source: (Field survey, 2023)

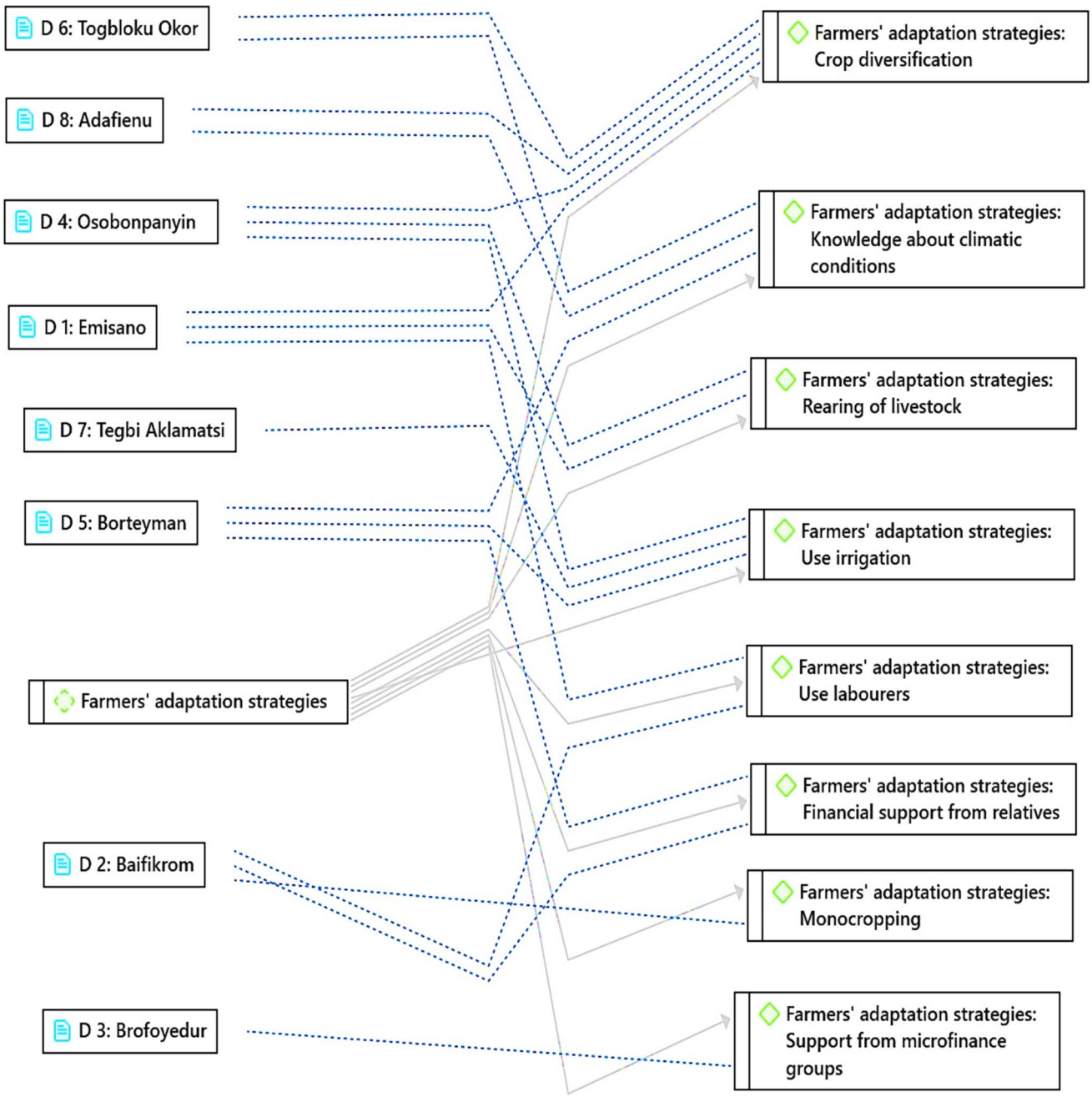

Fig. 3 A network of themes and constructs related to farmers' adaptation strategies in the study communities

as cucumbers. Cucumber farming is very fast. It takes a month and two weeks to mature, and you can sell it to get your money. If I want to take a break from the green pepper farming, I plant cucumber, which is easier to work on than this green pepper (D4: Osobonpanyin).

Some participants, particularly those residing in Borteyman, Togbloku Okor, and Adafienu, have years of experience in farming and possess knowledge regarding the climatic conditions specific to their areas. To strategically plant their crops, they rely on their knowledge of climatic conditions and seasonal variations. Within this particular adaptation strategy, a participant conveyed: "Every season has its own crop to grow. If you grow a particular crop at the wrong time, it will die, and you will not get back the money you put in." A participant again stated that he plants his crops close to the months of May, June, and July (the major season), where rainfall is reliable. Another participant whose understanding of the climatic conditions

helps him to save money by avoiding the need for frequent irrigation, reported that

> It is not common for the rain to come this month (March). Probably next month (April) or May. During these months, we have more rainfall and less irrigation. That also saves us some money. Even if it rains, we still irrigate the land because the land here dries up quickly as the temperatures continue to rise every day (D5: Borteyman).

The participants in the communities of Emisano and Osobonpanyin rear livestock such as goats as an adaptation strategy along with crop diversification, which fetches them money. The participants, particularly those in the communities of Osobonpanyin, Borteyman, and Tegbi Aklamatsi, appeared to use irrigation as a major adaptation strategy. A participant mentioned that he farms all year because he has an irrigation network on his farm. Again, a participant shared that he irrigates his crops with water from a nearby dam, but it is costly. Another participant who has no river or dam near his farm stated that he irrigates his crops with pipe-borne water, which he believes is bad for his crops because of the high ion content. The participants in Emisano and Baifikrom employ farm labourers because they cannot undertake their farm activities alone, especially during harvest. Some of the participants, especially those in the communities of Baifikrom and Borteyman, also receive financial support from their friends and relatives. They consider this important because it helps them adapt. Regarding this matter, a participant indicated that he borrows money from his brother, a public sector employee, who has easier access to loans from banks than him. Aside from this support network, some of the participants also receive assistance from microfinance groups. One participant stated that he and his wife have joined a "susu" (savings and loans) group that provides them with loans. The participant further noted that he can borrow once, and the amount is not huge, and he can borrow again after paying the previous loan.

Barriers that limit participants' adaptation strategies

Figure 4 depicts the graphical representation of the themes and constructs an analysis of barriers that limit participants' adaptation strategies based on interview data derived from the eight farmers who were considered key informants to the study. Figure 4 indicates that the participants encounter several barriers to their adaptation decisions. These barriers include lack of government support, financial constraints, high prices of farm inputs, lack of agricultural extension services, farm losses, the size of farmland, inadequate support from financial institutions (banks), bureaucracy in securing bank loans, the need for irrigation systems, the need for the right adaptation measures, the need for high-quality research institutions, and poor soil nutrients. The network of barriers ranges from a high lack of government support to a low level of farm losses and farmland size.

Figure 4 also reveals a connection between some of the barriers identified. For example, the lack of agricultural extension services and the need for high-quality research institutions are part of the lack of government support. Again, the need for the right adaptation measures and poor soil nutrients are part of farm losses. Inadequate support from financial institutions (banks) and bureaucracy in securing bank loans is also part of financial constraints.

Most of the participants lamented the lack of government support. According to these participants, a lack of government support encompasses several other supports, such as improved agricultural extension services and high-quality research institutions. One participant lamented about the lack of institutional support. A participant again stated that the farmers in his municipality do not receive training from anyone, and that no extension officer has ever been to his farm. Additionally, one farmer lamented about the inadequate, high-quality research institutions that give signals to the farmers on what the season will be like each year. Another farmer shared a similar worry, stating that

> For me, institutional failure is a major problem, despite the incidence of climate change. There should be the right instructions to help us, the farmers, with our adaptation strategies. Why is it that in Burkina Faso, there are tomatoes all year? Perhaps their research institutions are working to help farmers find the right species to grow, unlike here in Ghana (D7: Tegbi Aklamatsi).

The participants again revealed financial constraints as a major barrier to their adaptation decisions. The participants assert that inadequate support from financial institutions (banks) and bureaucracies in securing bank loans further complicates this adaptation barrier. A participant expressed that he cannot do the farming business without having money. A participant again stated that crops such as maize require regular weeding, and it is not easy for him to get money to pay labour costs or buy farm inputs. A participant who has the desire to cultivate more crops noted: "I wish I had more land to plant more, but I cannot afford the price." The participants were also worried about the inadequate support they received from financial institutions and the bureaucracy for securing bank loans. One participant stated that a bank asked him for collateral before they would give him a loan, which he could not afford. Another participant who was able to secure a loan from the bank indicated that the process is tedious; however, he said that if farmers take their time and present the right documents about their farm, they

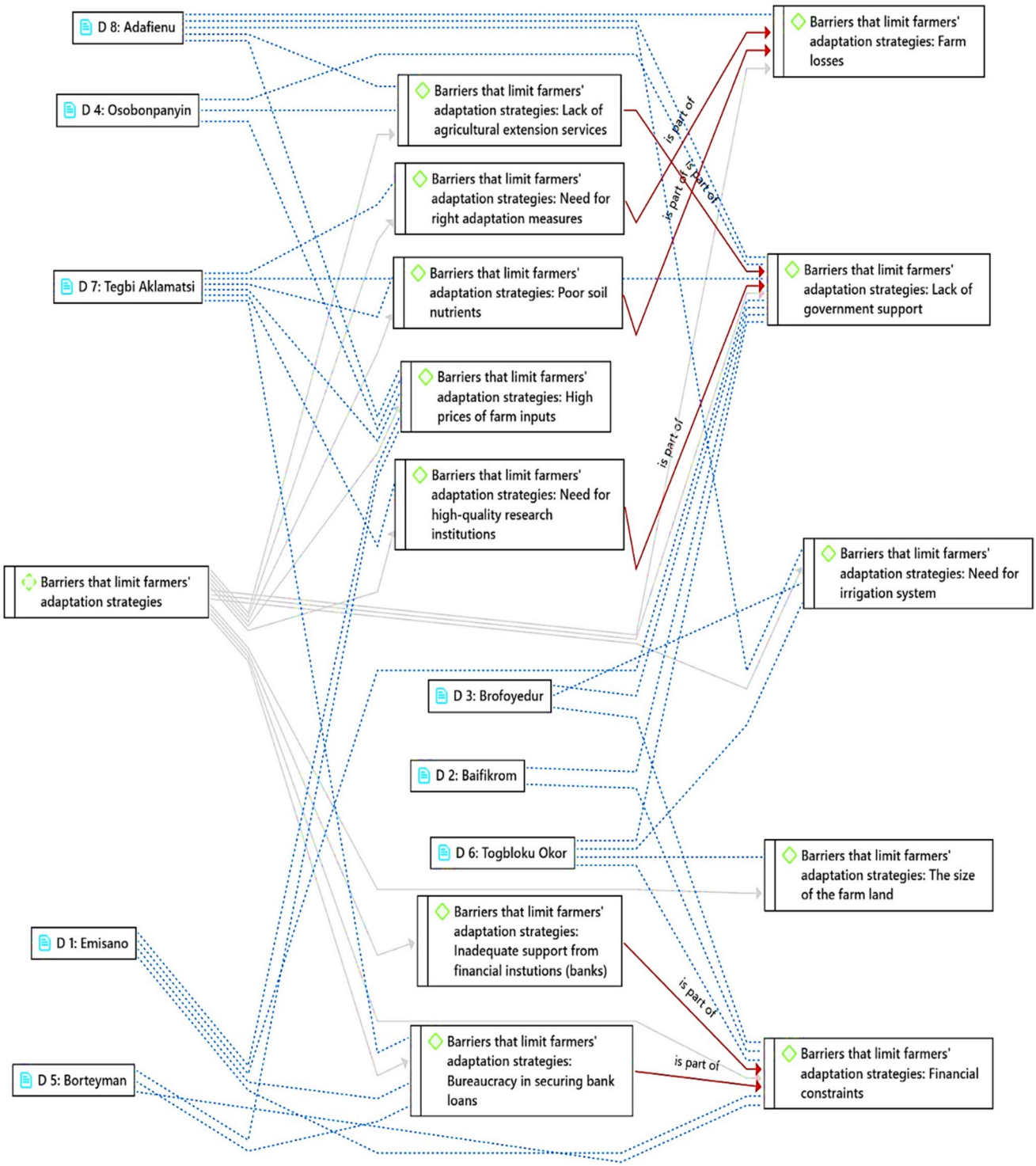

Fig. 4 A network of themes and constructs related to farmers' barriers that limit their adaptation strategies in the study communities

will get the loan they want from the banks. The participants considered the high prices of farm inputs a major concern, as they rely heavily on these inputs for their activities to boost production. On this issue, the participants lamented the high prices of fertilisers and manure, and they urged the government to do something about it to ensure food security in the country. Still on this issue, a participant noted: "The fertilisers are very expensive. The cost of manure, which should be more affordable, has also risen. When we

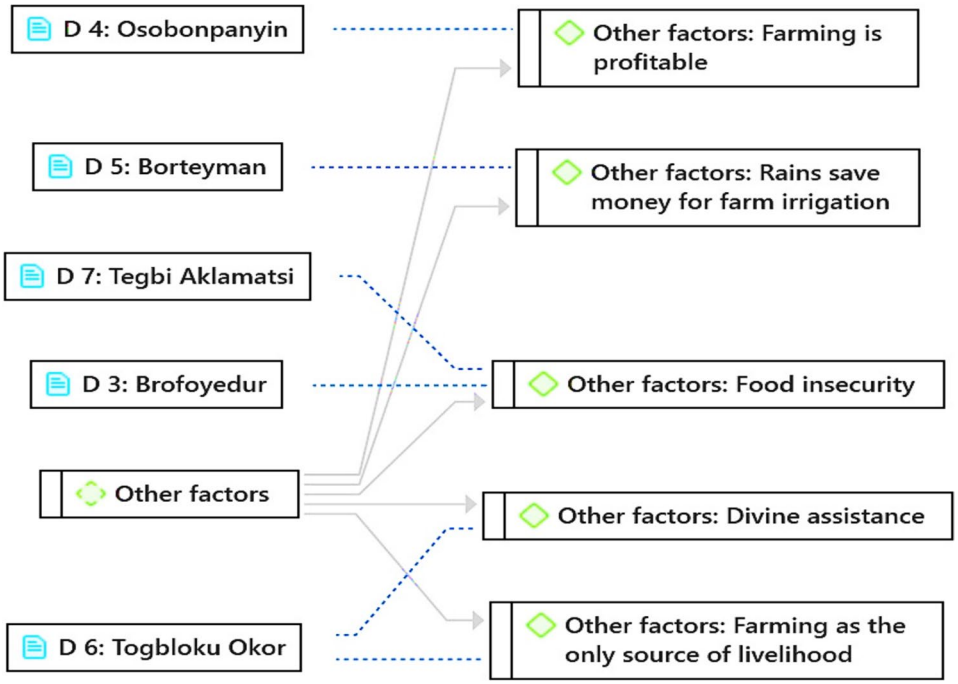

Fig. 5 A network of themes and constructs related to other factors that aid or hinder farmers'adaptation strategies in the study communities

buy fertiliser, instead of spreading it on the farm, we take handfuls and place them on the crop, which is not the best practice."

Some of the participants also expressed concerns about the need for irrigation systems, which they considered a barrier to their adaptation. These participants recognised the value of the use of irrigation even though they did not have access to one. One participant reported that it is better for him to irrigate his crop, but he cannot afford it as there is no river nearby his farm. Regarding the issue of land size, a participant expressed regret over his limited farmland, stating that it is not sufficient for his needs and that he must cultivate various crops on it. The participants complained about farm losses, which they attributed to poor soil nutrients. Regarding this matter, a participant expressed concern and advocated for the implementation of appropriate adaptation measures by stating that

> The pipe-borne water contains ions that harm soil and crops. Even if you use fertiliser, it still does not provide support because the soil here is deficient in nutrients…. Although climate change is a major problem, having the right adaptation measures, like fertiliser applications, will help, but we do not have them (D7: Tegbi Aklamatsi).

Other factors that aid or hinder participants' adaptation strategies

Figure 5 displays the graphical representation of the themes and constructs an analysis of other factors that aid or hinder participants' adaptation strategies based on interview data derived from the eight farmers who were considered key informants to the study. According to Fig. 5, the participants identified several other factors that aid or hinder their adaptation strategies. One of the participants underscored that farming is a profitable venture that everybody, especially youth, should consider undertaking. Another participant pointed out that rainfall reduces the cost of irrigation. Some participants argued that there will be food insecurity in the country due to the low irrigation system utilisation and the wrong adaptation choices. Another participant depends solely on farming for a livelihood and strongly believes in divine (God) assistance in his activities. A participant expressed concern about farming as a profitable venture and noted: "There is money in farming, but people have not realised it." A participant raised concerns about food insecurity, stating

> …If the government wants to see food in the market every day, then they should take agriculture seriously. Something like maize, if we have irrigation systems, we can grow crops like maize all year round. To me, there should not be a shortage of maize in the country. The same applies to some vegetable crops, like tomatoes (D3: Brofoyedur).

Table 6 Binary logistic regression showing the relationship between independent variables and adaptation strategies of farmers

Variables	B	S.E	Wald	df	Sig	Exp(B)	95% C.I. for EXP (B)	
							Lower	**Upper**
Adaptation strategy: Cultivate different types of crops								
Age	−0.059	0.124	0.225	1	0.635	0.943	0.739	1.203
Gender	0.530	0.187	8.050	1	0.005[a]	1.698	1.178	2.448
Education	0.157	0.091	3.001	1	0.083	1.170	0.980	1.398
Years of farming	0.078	0.081	0.933	1	0.334	1.081	0.923	1.266
Constant	−1.480	0.542	7.464	1	0.006[a]	0.228		
Nagelkerke (*pseudo* R^2)	0.025							
Adaptation strategy: Fertilizer application								
Age	−0.395	0.163	5.865	1	0.015[a]	0.674	0.489	0.927
Gender	0.158	0.292	0.295	1	0.587	1.172	0.661	2.075
Education	0.747	0.152	24.278	1	0.000[a]	2.110	1.568	2.840
Years of farming	0.038	0.114	0.114	1	0.736	1.039	0.831	1.300
Constant	−3.105	0.823	14.232	1	0.000[a]	0.045		
Nagelkerke (*pseudo* R^2)	0.094							
Adaptation strategy: Plant improved variety of seeds								
Age	0.751	0.221	11.542	1	0.001[a]	2.119	1.374	3.268
Gender	−0.669	0.231	8.373	1	0.004[a]	0.512	0.326	0.806
Education	−0.805	0.130	38.445	1	0.000[a]	0.447	0.347	0.577
Years of farming	−0.342	0.115	8.869	1	0.003[a]	0.710	0.567	0.890
Constant	0.188	0.776	0.058	1	0.809	1.206		
Nagelkerke (*pseudo* R^2)	0.167							
Adaptation strategy: Rearing of livestock								
Age	1.045	0.343	9.307	1	0.002[a]	2.844	1.453	5.565
Gender	−0.288	0.388	0.551	1	0.458	0.750	0.350	1.604
Education	1.015	0.281	13.027	1	0.000[a]	2.760	1.590	4.790
Years of farming	0.032	0.178	0.031	1	0.859	1.032	0.728	1.464
Constant	−7.636	1.411	29.308	1	0.000[a]	0.000		
Nagelkerke (*pseudo* R^2)	0.088							
Adaptation strategy: Use irrigation								
Age	0.285	0.204	1.959	1	0.162	1.330	0.892	1.984
Gender	0.070	0.258	0.075	1	0.785	1.073	0.647	1.780
Education	−0.580	0.134	18.690	1	0.000[a]	0.560	0.431	0.728
Years of farming	0.079	0.121	0.431	1	0.511	1.083	0.854	1.372
Constant	−1.521	0.787	3.736	1	0.053	0.218		
Nagelkerke (*pseudo* R^2)	0.051							

[a]Significant at 0.05. Source: (Field survey, 2023)

Odds of choosing a specific adaptation strategy using binary logistic regression

The binary logistic regression analysis shows that gender is a significant predictor ($p=0.005$) of whether or not respondents would cultivate different kinds of crops as a way to adapt (Table 6). The Nagelkerke (*pseudo* R^2) is 0.025, showing that gender accounts for only 2.5% of the variations in respondents' adoption of different types of crops as an adaptation strategy. Based on their gender, the odds of respondents choosing to cultivate different types of crops as an adaptation strategy increase by 1.698. The use of fertiliser as an adaptation strategy was significantly predicted by age ($p=0.015$) and education ($p=0.001$). The *pseudo* R^2 is 0.094, indicating that age and education account for just 9.4% of the variation in respondents' use of fertiliser as an adaptation strategy. Based on their age and education, the odds of respondents choosing to use fertiliser as an adaptation strategy increase by 0.674 and 2.110, respectively. Similarly, age ($p=0.002$) and education ($p=0.001$) predicted respondents' adoption of livestock rearing as an adaptation strategy. The *pseudo* R^2 is 0.088, implying that age and education account for only 8.8% of the

variations in respondents' adoption of raising livestock as an adaptation strategy. Based on their age and education, the odds of respondents choosing to raise livestock as an adaptation strategy increase by 2.844 and 2.760, respectively.

Age ($p=0.001$), gender ($p=0.004$), education ($p=0.001$), and years of farming ($p=0.003$) all predicted respondents' choice to plant improved varieties of seeds as an adaptation strategy. The *pseudo* R^2 is 0.691, indicating that age and education account for 69.1% of the variations in respondents' preferences for planting improved seed varieties as an adaptation strategy. The odds of choosing to plant improved varieties of seeds as an adaptation strategy increase with age by 2.119, gender by 0.512, education by 0.447, and years of farming by 0.710. Education was the only factor that significantly predicted irrigation as an adaptation strategy ($p<0.001$). The *pseudo* R^2 is 0.051, indicating that education explains only 5.1% of the variations in respondents' use of irrigation as an adaptation strategy. Based on their education, the odds of using irrigation as an adaptation strategy increase by 0.560. Although the model is a significant predictor of the dependent variable (the various adaptation strategies), given the small variations in the model provided by the *pseudo* R^2, other significant predictors may exist.

Discussion

This study examined smallholder farmers' perceptions of climate risks and adaptation strategies in the coastal Savannah agroecological zone of Ghana. The agricultural sector of many land economies faces substantial risks from climate change and variability, thereby threatening global food security and the livelihoods of people (Brink et al. 2023; Wang et al. 2018). Farmers, particularly those in developing countries, face critical difficulties due to their climate-sensitive agricultural practises and limited capacity for adaptation (IPCC 2014; Yaro 2013). The significance of farmers' perceptions regarding the risks associated with climate change and variability is equally as crucial as the resultant impacts. Consequently, it is imperative to conduct research utilising a bottom-up approach in order to comprehend the societal perspectives on climate change and variability, as well as the adaptive and coping strategies employed by people. specifically, those engaged in small-scale farming.

The results revealed that there has been a notable increase in smallholder farmers' awareness and understanding of climate change and variability. This positive change can be attributed to the enhanced dissemination of information through broadcast media platforms such as television and radio. This finding is consistent with the previous research conducted by Obossou et al. (2023) in the northern region of Benin and Manandhar et al. (2011) in the Rupandehi district of Nepal. The farmers attributed climate change and variability primarily to negative human actions, aligning with the prevailing scientific consensus (IPCC 2014). The gendered dimension of information availability in farmers' awareness and understanding of climate change indicated that both men and women farmers used television more than radio. However, a large number (87%) of men used television more than women (68%). Although both men and women identified deforestation as a major contributor to climate change and variability, the proportions ranged from 83% for men to 54% for women. While the findings are consistent with previous studies by Memon et al. (2023) in Pakistan and Partey et al. (2020) in Northern Ghana, they contradict those of Issa et al. (2015), who reported that personal experiences were the primary source of climate change awareness and understanding among farmers in Nigeria's north-central and north-west agroecological zones. The present study provides a unique contribution to the existing literature by offering a comprehensive and detailed analysis of the farmers' climate risk perception and adaptation strategies in the coastal Savannah agroecological zone. Although the findings align with previous studies conducted in different contexts, this study shows its originality in examining the farmers' perspectives, understandings, and experiences on climate risk and strategies for adaptation in the coastal Savannah agroecological zone, where no study of such nature existed. The study's findings are consistent with and support the existing scientific consensus in the broader literature regarding the increasing adverse effects of climate risks on agricultural activities. This underscores the need for enhanced adaptation strategies across different countries and scales. Farmers have identified deforestation as the primary factor that contributes to climate change and variability. The findings of this study align with the previous research conducted by Codjoe et al. (2014) in Ghana and in the eastern portion of the Amazon, Brazil, by Gatti et al. (2021). The viewpoints of farmers regarding rising temperatures in the region, as well as changes in hot and cold periods, agree with the findings of Batungwanayo et al. (2023) in northeastern Burundi and the IPCC AR5 (Bindoff et al. 2013; IPCC 2014). The perspectives regarding the increase in hot periods and decrease in cold periods within the zone agree with the previous study conducted by Ankrah et al. (2023b). The farmers perceived a decrease in the total annual rainfall in the zone, along with an increase in the intensity of rainfall events.

The analysis of climatic variables revealed greater variability in rainfall patterns across the zone. Previous studies, such as those conducted by Fosu-Mensah et al. (2012), Lawson et al. (2020), and Yamba et al. (2019), have reported the perceptions of farmers regarding the perceived decrease and erratic rainfall in other parts of Ghana, in the Kirundo and Muyinga in northeastern Burundi by Batungwanayo et al. (2023), and in the northern Ethiopian highlands by Hubertus et al. (2023). According to the IPCC's AR5, the SSA region

is expected to experience more erratic rainfall, which could have adverse impacts on crop productivity, pose a threat to food security, and impact the livelihoods of farmers (IPCC 2014). Previous studies by Ntim-Amo et al. (2022) and Yiridomoh et al. (2021) found an increased perception of extreme rainfall events among farmers in Ghana's Sudan and Guinea Savannah agroecological zones. The farmers perceived a decrease in rainfall over the past two decades; however, a study conducted by Ankrah et al. (2023b) indicates that there is a projected increase in rainfall. According to the farmers, there has been an observed increase in the overall wind speed, particularly during the dry season, over the past two decades. The findings of the spatial distribution analysis of wind speed provided support for their assertions, indicating an overall increase in wind speed and a greater degree of variability in the zone.

Again, the farmers perceive extreme temperatures, drought, pests and diseases as the major climate risks that have an impact on their agricultural practices. The major effects associated with temperature risks include the ripening of unmature crops and the drying of crops or seedlings. The farmers have identified a decrease in crop yield as the main impact of changes in rainfall on their agricultural practices. These findings are consistent with the earlier studies conducted by Yaro (2013) in Ghana, by Shah et al. (2023) in Pakistan, and by Tasnim et al. (2023) in northwest Bangladesh. According to the study by Rowhani et al. (2011), variations in temperature and precipitation, both within and between seasons, have a significant impact on cereal crop yields in Tanzania. The main effects of wind speed and extreme events, as determined by the farmers, include crop destruction, losses, and low productivity. This is consistent with the previous studies conducted by Ntim-Amo et al. (2022), Yiridomoh et al. (2021) in other parts of Ghana, in the U.S.A. by Yaddanapudi and Mishra (2022), and in China by Zhang et al. (2017). The farmers believe that the increased risks posed by climate change and variability in their agricultural methods have led to poverty, thereby impacting their means of livelihood and contributing to food insecurity in the country. These assertions made by the farmers support previous studies conducted by Aydinalp and Cresser (2008), Aryal et al. (2020), Brink et al. (2023), Hallegatte and Rozenberg (2017), Hounnou et al. (2023), Zhang et al. (2023), and the IPCC AR5 (IPCC 2014).

The results also showed that the smallholder farmers employed various adaptation or coping strategies, especially the practice of cultivating different crops on a single plot of land and the use of improved seed varieties for planting purposes. The findings are consistent with previous studies conducted in other parts of Ghana, such as those of Asravor (2018), Fosu-Mensah et al. (2012), Sadiq et al. (2019), Yamba et al. (2019), Yaro (2013), and Yiridomoh et al. (2021), and elsewhere, including those of Shah et al. (2023), Tasnim et al. (2023), Batungwanayo et al. (2023), Fahim and Sikder (2022), and Metcalfe et al. (2020). The farmers have identified a number of obstacles that impede their farming activities, with financial constraints and high costs of farm inputs or fertilisers being the main obstacles. This finding agrees with previous studies conducted by Yaro (2013), Batungwanayo et al. (2023), and Shah et al. (2023). The results of the binary logistic regression analysis revealed that the socio-demographic characteristics, namely age, gender, education, and years of farming experience, were found to be significant predictors of the farmers' decision to adopt or employ various adaptation or coping strategies. These strategies included cultivating different types of crops, using fertilisers, engaging in livestock rearing, adopting improved seed varieties, and employing irrigation techniques. This finding is consistent with previous studies conducted by Shah et al. (2023).

This study's limitations include the lack of a sample frame to determine the minimum required sample size for the study communities. This was due to a lack of official records indicating the total number of smallholder farmers in the various municipalities or districts. This could affect how representative the study results are for various study communities and the entire zone. However, the unbiased nature of the sample process, in which 100 farmers were selected from each of the eight communities, ensures fairness and allows for generalisation of the study findings. Lawson et al. (2020) encountered a similar challenge in determining the minimum required sample size for their study on the intersectional perceptions and adaptation strategies of women smallholder farmers in Ghana's Upper West region, as there were no official records available. Also, all eight participants selected for the interview were male, indicating a disparity in gender representation. However, at least five respondents, including the females who participated in the questionnaire survey in each community, identified these key informants. Further research that examines the influence of factors such as farm size, income, credit access, extension services, household size, social networks, information, and social status on the perceptions and adaptation strategies of farmers, particularly women farmers, and the power dynamics they face in accessing resources would be beneficial and contribute to informed policy decisions for the farmers in the zone.

Conclusion

This study examined smallholder farmers' perceptions of climate risks and adaptation strategies in the coastal Savannah agroecological zone of Ghana. The main findings indicate a noticeable increase in understanding and awareness of climate change and variability among farmers. The farmers

attributed climate change and variability to negative human actions. The farmers perceived increasing temperatures, hot periods, and decreasing cold periods, as well as a decrease in the total annual rainfall accompanied by a rise in the intensity of rainfall events across the zone. The findings are consistent with the existing body of scientific literature. The farmers' agricultural practises are adversely impacted by climate risks, such as extreme temperatures, drought, and the proliferation of pests and diseases. The effects that result from these risks include the ripening of unmature crops, the drying of crops or seedlings, a decrease in crop yield, crop destruction, losses, and low productivity. The assertion made by the farmers suggests that the increase in climate risks has resulted in both poverty and food insecurity in the country.

Regardless of the increased risks, the findings indicate that smallholder farmers have implemented various adaptation strategies, such as cultivating different crops on a single plot of land, using improved seed varieties for planting, using fertilisers, and rearing livestock, among others. Despite the adoption of various adaptation strategies by farmers, they encounter numerous obstacles that hinder their farming activities. The obstacles include a range of challenges, such as increased financial constraints, high costs of farm inputs, inadequate government support, and poor extension services, among others.

The findings above have major consequences for the agricultural practises of smallholder farmers in the zone, specifically in relation to the changes in climatic variables. It is anticipated that the majority of risks arising from changes in temperature, rainfall, and related extreme events will persist within the zone. However, the development of an early warning system, increased awareness through mass media, and improved academic engagement in addressing existing and potential risks may prove beneficial for farmers. The improved understanding of the risks resulting from changes in temperature, rainfall, droughts, and floods among farmers will serve as a basis for their informed choices regarding adaptations or coping strategies. The limited implementation of these initiatives for farmers results in a greater tendency for maladaptation, potentially leading to increased risk and resulting negative effects on their livelihoods. Based on the findings of the study, it is evident that the smallholder farmers have already implemented at least one adaptation or coping strategy. However, they are faced with various constraints that limit their ability to adapt or cope, thus necessitating policy interventions and support. It is advised that financial institutions, including both public and private entities, undertake a reduction in interest rates applicable to loans and enhance the flexibility of loan acquisition procedures, with a specific focus on catering to the needs of farmers, particularly smallholder farmers. Ghana's patriarchal society necessitates the implementation of targeted policies by the government and financial institutions, specifically designed to support women farmers. These policies should address the domination faced by women, as well as their limited access to resources such as land and capital and the unequal power dynamics they encounter. It is recommended that the government, through the ministry of food and agriculture, consider implementing subsidies for farm inputs, with a particular focus on fertilisers, in order to enhance affordability and availability for farmers. Taking a step in this particular direction would consequently contribute to the enhancement of the economic status, the safeguarding of agricultural practises, and the improvement of the livelihoods of the farmers.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13412-024-00970-w.

Acknowledgements This study is part of the Ph.D. research project 'Assessing climate change and climate variability impacts in the coastal savannah agroecological zone of Ghana' and I acknowledge the support of the Portuguese Foundation for Science and Technology (Fundação para a Ciência e Tecnologia)-FCT under the PhD research grant (https://doi.org/10.54499/2021.05220.BD).

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Johnson Ankrah]. The first draft of the manuscript was written by [Johnson Ankrah] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding No funding was received for conducting this study.

Data availability The data used in this study is available upon request.

Declarations

Ethics approval The ethics commission of the Faculty of Arts and Humanities at the University of Porto provided approval for the conduct of the study with resolution No. 31/CEFLUP/.

Informed consent The research ethics commission of the Faculty of Arts and Humanities at the University of Porto reviewed and provided approval for the data collection instruments used in the study. Prior to the start of the interview, the participant was provided with a consent form that outlined their rights as a participant, such as the voluntary nature of the interview and their prerogative to withdraw from the study or request the removal or deletion of their previously recorded responses.

Competing interest The authors declare no competing of interest.

References

Abid M, Scheffran J, Schneider UA, Ashfaq M (2015) Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province. Pakistan Earth Syst Dynam 6:225–243. https://doi.org/10.5194/esd-6-225-2015

Addi M, Asare K, Fosuhene SK, Ansah-Narh T, Aidoo K, Botchway CG (2021) Impact of large-scale climate indices on

meteorological drought of Coastal Ghana. Advances in Meteorology vol. 2021, ID 8899645:17. https://doi.org/10.1155/2021/8899645

Adesete AA, Olanubi OE, Dauda RO (2023) Climate change and food security in selected Sub-Saharan African countries. Environ Dev Sustain 25:14623–14641. https://doi.org/10.1007/s10668-022-02681-0

Ado AM, Leshan J, Savadogo P, Bo L, Shah AA (2019) Farmers' awareness and perception of climate change impacts: case study of Aguie district in Niger. Environ Dev Sustain 21:2963–2977. https://doi.org/10.1007/s10668-018-0173-4

Ado AM, Savadogo P, Pervez AKMK, Mudimu GT (2020) Farmers' perceptions and adaptation strategies to climate risks and their determinants: insights from a farming community of Aguie district in Niger. GeoJournal 85:1075–1095. https://doi.org/10.1007/s10708-019-10011-7

Akinsanola AA, Ogunjobi KO, Abolude AT, Salack S (2021) Projected changes in wind speed and wind energy potential over West Africa in CMIP6 models. Environ Res Lett. 16(4):04403. https://doi.org/10.1088/1748-9326/abed7a

Akinyi DP, Karanja Ng'ang'a S, Girvetz EH, (2021) Trade-offs and synergies of climate change adaptation strategies among smallholder farmers in sub-Saharan Africa: A systematic review. Regional Sustainability 2(2):130–143. https://doi.org/10.1016/j.regsus.2021.05.002

Alhassan U, Haruna EU (2024) Rural farmers' perceptions of and adaptations to climate change in Sub-Saharan Africa: Does climate-smart agriculture (CSA) matter in Nigeria and Ethiopia?. Environ Econ Policy Stud 2024. https://doi.org/10.1007/s10018-023-00388-8

Aloysius NR, Sheffield J, Saiers JE, Li H, Wood EF (2016) Evaluation of historical and future simulations of precipitation and temperature in central Africa from CMIP5 climate models. Journal of Geophysical Research: Atmospheres 121(1):130–152. https://doi.org/10.1002/2015JD023656

Amadou T, Falconnier GN, Mamoutou K, Georges S, Alassane BA, François A, Michel G, Benjamin S (2022) Farmers' perception and adaptation strategies to climate change in Central Mali. Weather, Climate, and Society 14(1):95–112. https://doi.org/10.1175/WCAS-D-21-0003.1

Amani RK, Riera B, Imani G, Batumike R, Zafra-Calvo N, Cuni-Sanchez A (2022) Climate change perceptions and adaptations among smallholder farmers in the mountains of Eastern Democratic Republic of Congo. Land 11(5):628. https://doi.org/10.3390/land11050628

Ankrah J, Monteiro A, Madureira H (2023a) Spatiotemporal characteristics of meteorological drought and wetness events across the Coastal Savannah agroecological zone of Ghana. Water 15(1):211. https://doi.org/10.3390/w15010211

Ankrah J, Monteiro A, Madureira H (2023b) Extreme temperature and rainfall events and future climate change projections in the coastal Savannah agroecological zone of Ghana. Atmosphere 14(2):386. https://doi.org/10.3390/atmos14020386

Antwi-Agyei P, Quinn CH, Adiku SGK, Codjoe SNA, Dougill AJ, Lamboll R, Dovie DBK (2017) Perceived stressors of climate vulnerability across scales in the Savannah zone of Ghana: a participatory approach. Reg Environ Change 17:213–227. https://doi.org/10.1007/s10113-016-0993-4

Archer ER, Landman WA, Tadross MA, Malherbe J, Weepener H, Maluleke P, Marumbwa FM (2017) Understanding the evolution of the 2014–2016 summer rainfall seasons in southern Africa: Key lessons. Clim Risk Manag 16:22–528. https://doi.org/10.1016/j.crm.2017.03.006

Arku G, Luginaah I, Mkandawire P (2012) "You either pay more advance rent or you move out": Landlords/ladies' and tenants' dilemmas in the low-income housing market in Accra. Ghana Urban Studies 49(14):3177–3193. https://doi.org/10.1177/0042098012437748

Aryal JP, Sapkota TB, Khurana R, Khatri-Chhetri A, Rahut DB, Jat ML (2020) Climate change and agriculture in South Asia: adaptation options in smallholder production systems. Environ Dev Sustain 22:5045–5075. https://doi.org/10.1007/s10668-019-00414-4

Asare-Nuamah P, Botchway E (2019) Understanding climate variability and change: Analysis of temperature and rainfall across agroecological zones in Ghana. Heliyon 5(10):e02654. https://doi.org/10.1016/j.heliyon.2019.e02654

Asravor R (2018) Smallholder farmers' risk perceptions and risk management responses: Evidence from the semi-arid region of Ghana. African J Econ Manag Stud 9(3):367–387. https://doi.org/10.1108/AJEMS-10-2017-0250

Aydinalp C, Cresser MS (2008) The effects of global climate change on agriculture. Am-Euras J Agric & Environ Sci 3(5):672–676

Ayeni MD, Adewumi MO (2023) Food security among cashew farming households in Kogi state, Nigeria. GeoJournal 88:3953–3968. https://doi.org/10.1007/s10708-023-10846-1

Bagambilana FR, Rugumamu WM (2023) Determinants of farmers' adaptation intent and adoption of adaptation strategies to climate change and variability in Mwanga district, Tanzania. Environ Manage 72:785–804. https://doi.org/10.1007/s00267-023-01792-2

Baidu M, Amekudzi LK, Aryee JNA, Annor T (2017) Assessment of long-term spatio-temporal rainfall variability over Ghana using wavelet analysis. Climate 5(2):1–24. https://doi.org/10.3390/cli5020030

Barbara J, Mudaliar C, Leach M, Amosa P, Tauaa S, Imo T (2023) Popular attitudes to climate change in the Pacific: the case of Samoa. Reg Environ Chang 23:81. https://doi.org/10.1007/s10113-023-02065-8

Barnett J, O'Neill S (2010) Maladaptation. Glob Environ Change 20(2):211–213. https://doi.org/10.1016/j.gloenvcha.2009.11.004

Batungwanayo P, Habarugira V, Vanclooster M, Ndimubandi JF, Koropitan A, Nkurunziza JDD (2023) Confronting climate change and livelihood: smallholder farmers' perceptions and adaptation strategies in northeastern Burundi. Reg Environ Change 23:47. https://doi.org/10.1007/s10113-022-02018-7

Bindoff NL, Stott PA, AchutaRao KM, Allen MR, Gillett N, Gutzler D, Hansingo K, Hegerl G, Hu Y, Jain S, Mokhov IL, Overland J, Perlwitz J, Sebbari JR, Zhang X (2013) Detection and attribution of climate change: from global to regional. In: Climate Change 2013: The Physical Science Basis. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Brink BT, Giesen P, Knoope P (2023) Future responses to environment-related food self-insufficiency, from local to global. Reg Environ Change 23:87. https://doi.org/10.1007/s10113-023-02069-4

Brügger A (2020) Understanding the psychological distance of climate change: The limitations of construal level theory and suggestions for alternative theoretical perspectives. Glob Environ Chang 60:102023. https://doi.org/10.1016/j.gloenvcha.2019.102023

Calzadilla A, Rehdanz K, Betts R, Falloon P, Wiltshire A, Tol RSJ (2013) Climate change impacts on global agriculture. Clim Change 120:357–374. https://doi.org/10.1007/s10584-013-0822-4

Célestin M, Emmanuel LA, Batablinlè L, Marc N (2019) Spatio-temporal analysis of climate change impact on future wind power potential in Burundi (East Africa). Am J Clim Chang 08(02):237–262. https://doi.org/10.4236/ajcc.2019.82014

Chaachouay N (2024) Zidane L (2024) Perceptions and strategies of adaptation of Moroccan farmers to climate change—case of

Khemisset province. J Environ Stud Sci. https://doi.org/10.1007/s13412-024-00889-2
Chichongue OJ, Karuku GN, Mwala AK, Onyango CM, Magalhaes AM (2015) Farmers risk perceptions and adaptation to climate change in Lichinga and Sussundenga. Mozambique African Journal of Agricultural Research 10(17):1938–1942. https://doi.org/10.5897/AJAR2013.7360
Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magaña Rueda V, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p pp 847-940
Codjoe SNA, Owusu G, Burkett V (2014) Perception, experience, and indigenous knowledge of climate change and variability: the case of Accra, a sub-Saharan African city. Reg Environ Change 14:369–383. https://doi.org/10.1007/s10113-013-0500-0
Creswell JW (2014) Research design: qualitative, quantitative, and mixed methods approaches, 4th edn. Thousand Oaks, California, Sage
Cudjoe GP, Antwi-Agyei P, Gyampoh BA (2021) The effect of climate variability on maize production in the Ejura-Sekyedumase municipality. Ghana Climate 9(10):145. https://doi.org/10.3390/cli9100145
Dasmani I, Darfor KN, Karakara AA (2020) Farmers' choice of adaptation strategies towards weather variability: Empirical evidence from the three agro-ecological zones in Ghana. Cogent Social Sciences 6(1):1751531. https://doi.org/10.1080/23311886.2020.1751531
Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global environmental change. 19(2):248–55. https://doi.org/10.1016/j.gloenvcha.2009.01.002
Dickson KB, Benneh G (2001) A new geography of Ghana, Revised. Longman Group Ltd., London, UK
Easterling WE (2007) Climate change and the adequacy of food and timber in the 21st century. Proc Natl Acad Sci USA 104(50):19679. https://doi.org/10.1073/pnas.0710388104
Ekwezuo CS, Ezeh CU (2020) Regional characterisation of meteorological drought and floods over west Africa. Sustain Water Resour Manag 6:80. https://doi.org/10.1007/s40899-020-00439-y
Eriksen SH, Nightingale AJ, Eakin H (2015) Reframing adaptation: The political nature of climate change adaptation. Glob Environ Chang 35:523–533. https://doi.org/10.1016/j.gloenvcha.2015.09.014
Fadina AMR, Barjolle D (2018) Farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. Environments 5(1):15. https://doi.org/10.3390/environments5010015
Fahim TC, Sikder BB (2022) Exploring farmers' perception of climate-induced events and adaptation practices to protect crop production and livestock farming in the Haor area of north-eastern Bangladesh. Theor Appl Climatol 148:441–454. https://doi.org/10.1007/s00704-021-03907-3
Fosu-Mensah BY, Vlek PLG, MacCarthy DS (2012) Farmers' perception and adaptation to climate change: A case study of Sekyedumase district in Ghana. Environ Dev Sustain 14:495–505. https://doi.org/10.1007/s10668-012-9339-7
Gatti LV, Basso LS, Miller JB, Gloor M, Domingues LG, Cassol HLG, Tejada G, Aragão LEOC, Nobre C, Peters W, Marani L, Arai E, Sanches AH, Corrêa SM, Anderson L, Randow CV, Correia CSC, Crispim SP, Neves RAL (2021) Amazonia as a carbon source linked to deforestation and climate change. Nature 595:388–393. https://doi.org/10.1038/s41586-021-03629-6
Gbegbelegbe S, Serem J, Stirling C, Kyazze F, Radeny M, Misiko M, Tongruksawattana S, Nafula L, Gakii M, Sonder K (2018) Smallholder farmers in Eastern Africa and climate change: a review of risks and adaptation options with implications for future adaptation programmes. Climate Dev 10(4):289–306. https://doi.org/10.1080/17565529.2017.1374236
Gebrechorkos SH, Hülsmann S, Bernhofer C (2019) Long-term trends in rainfall and temperature using high-resolution climate datasets in East Africa. Sci Rep 9:11376. https://doi.org/10.1038/s41598-019-47933-8
Ghana Statistical Service (2013) 2010 Population and housing census. National analytical report. https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/2010_PHC_National_Analytical_Report.pdf. Accessed 8 Aug 2023
Glaus A, Mosimann M, Röthlisberger V, Ingold K (2020) How flood risks shape policies: flood exposure and risk perception in Swiss municipalities. Reg Environ Change 20:120. https://doi.org/10.1007/s10113-020-01705-7
Griffin RJ, Yang Z, ter Huurne E, Boerner F, Ortiz S, Dunwoody S (2008) After the flood: anger, attribution, and the seeking of information. Sci Commun 29(3):285–315. https://doi.org/10.1177/1075547007312309
Haile GG, Tang Q, Hosseini-Moghari SM, Liu X, Gebremicael TG, Leng G, Kebede A, Xu X, Yun X (2020) Projected impacts of climate change on drought patterns over East Africa. Earth's Future 8:e2020EF001502. https://doi.org/10.1029/2020EF001502
Hallegatte S, Rozenberg J (2017) Climate change through a poverty lens. Nature Clim Chang 7:250–256. https://doi.org/10.1038/nclimate3253
Hay I (2010) Qualitative research methods in human geography, 3rd edn. Oxford University Press, Oxford
Hitz S, Smith J (2004) Estimating global impacts from climate change. Glob Environ Chang 14(3):201–218. https://doi.org/10.1016/j.gloenvcha.2004.04.010
Holmes AGD (2020) Researcher positionality 1A consideration of its influence and place in qualitative research A new researcher guide. Shanlax International Journal of Education. 8(4):1–10. https://doi.org/10.34293/education.v8i4.3232
Hossain MS, Alam GMM, Fahad S, Sarker T, Moniruzzaman M, Rabbany MG (2022) Smallholder farmers' willingness to pay for flood insurance as climate change adaptation strategy in northern Bangladesh. J Clean Prod 338:130584. https://doi.org/10.1016/j.jclepro.2022.130584
Hounkpè J, Badou DF, Ahouansou DMM, Totin E, Sintondji LOC (2022) Assessing observed and projected flood vulnerability under climate change using multi-modeling statistical approaches in the Ouémé River Basin, Benin (West Africa). Reg Environ Change 22:112. https://doi.org/10.1007/s10113-022-01957-5
Hounnou FE, Houessou AM, Dedehouanou H (2023) Farmers' preference and willingness to pay for weather forecast services in Benin (West Africa). Reg Environ Change 23:77. https://doi.org/10.1007/s10113-023-02058-7
Hubertus L, Groth J, Teucher M, Hermans K (2023) Rainfall changes perceived by farmers and captured by meteorological data: two sides to every story. Reg Environ Change 23:75. https://doi.org/10.1007/s10113-023-02064-9
IPCC (2007) Climate Change 2007: *Impacts, Adaptation and Vulnerability*. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, p 976

IPCC (2014) Climate change: 2014 impacts, adaptation, and vulnerability. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p pp. 688

IPCC (2019) *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

IPCC (2022) Climate Change 2022: *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3056. https://doi.org/10.1017/9781009325844

Issa FO, Tologbonse BE, Olaleye R, Tologbonse OM, Kagbu JH (2015) Farmers' perception of climate change and coping strategies across gender in two agro-ecological zones of Nigeria. Journal of Agricultural Extension 19(1):35–48. https://doi.org/10.4314/jae.v19i1.3

Jairo M, Korir E (2019) Climate knowledge, adaptation and intensity of adaptation strategies among farmers in the slopes of Mount Kenya. Climatol Weather Forecasting 7:246

Jaiswal RK, Lohani AK, Tiwari HL (2015) Statistical analysis for change detection and trend assessment in climatological parameters. Environ Process 2:729–749. https://doi.org/10.1007/s40710-015-0105-3

Johnson D, Parsons M, Fisher K (2023) Adaptation at whose expense? Explicating the maladaptive potential of water storage and climate-resilient growth for Māori women in northern Aotearoa. Glob Environ Chang 82:102733. https://doi.org/10.1016/j.gloenvcha.2023.102733

Juana JS, Kahaka Z, Okurut FN (2013) Farmers' perceptions and adaptations to climate change in sub-Sahara Africa: A synthesis of empirical studies and implications for public policy in African agriculture. J Agric Sci 5(4):121. https://doi.org/10.5539/jas.v5n4p121

Kabir MH, Hossain KZ, Azad MJ, Tan ML (2022) Farmers' climate change risk perception, adaptation capacity and barriers to adaptation: a multi-method approach. J Environ Stud Sci 12:769–778. https://doi.org/10.1007/s13412-022-00779-5

Kapuka A, Hlásny T, Helmschrot J (2022) Climate change research in southern Africa in recent two decades: progress, needs, and policy implications. Reg Environ Change 22:18. https://doi.org/10.1007/s10113-022-01886-3

Karl TR, Trenberth KE (2003) Modern global climate change. Science 302(5651):1719–1723. https://doi.org/10.1126/science.1090228

Krefting L (1991) Rigor in qualitative research: The assessment of trustworthiness. Am J Occup Ther 45(3):214–222. https://doi.org/10.5014/ajot.45.3.214

Kusow AM (2003) Beyond indigenous authenticity: Reflections on the insider/outsider debate in immigration research. Symb Interact 26:591–599. https://doi.org/10.1525/si.2003.26.4.591

Lawson ET, Alare RS, Salifu ARZ, Thompson-Hall M (2020) Dealing with climate change in semi-arid Ghana: understanding intersectional perceptions and adaptation strategies of women farmers. GeoJournal 85:439–452. https://doi.org/10.1007/s10708-019-09974-4

Liu J, Fritz S, van Wesenbeeck CFA, Fuchs M, You L, Obersteiner M, Yang H (2008) A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change. Global Planet Change 64(3–4):222–235. https://doi.org/10.1016/j.gloplacha.2008.09.007

Manandhar S, Vogt DS, Perret SR, Kazama F (2011) Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices. Reg Environ Change 11:335–348. https://doi.org/10.1007/s10113-010-0137-1

Mba WP, Longandjo GNT, Moufouma-Okia W, Bell JP, James R, Vondou DA, Haensler A, Fotso-Nguemo TC, Guenang GM, Tchotchou ALD, Kamsu-Tamo PH, Takong RR, Nikulin G, Lennard CJ, Dosio A (2018) Consequences of 1.5 °C and 2 °C global warming levels for temperature and precipitation changes over Central Africa. Environmental Research Letters 13:055011. https://doi.org/10.1088/1748-9326/aab048

Memon FS, Abdullah FB, Iqbal R, Ahmad S, Hussain I, Abdullah M (2023) Addressing women's climate change awareness in Sindh, Pakistan: an empirical study of rural and urban women. Climate Dev 15(7):565–577. https://doi.org/10.1080/17565529.2022.2125784

Mertz O, Mbow C, Reenberg A, Diouf A (2009) Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. Environ Manage 43:804–816. https://doi.org/10.1007/s00267-008-9197-0

Metcalfe SE, Schmook B, Boyd DS, De la Barreda-Bautista B, Endfield GE, Mardero S, Che MM, González RM, Gill MTM, Olmedo SN, Perea A (2020) Community perception, adaptation and resilience to extreme weather in the Yucatan Peninsula. Mexico Reg Environ Change 20:25. https://doi.org/10.1007/s10113-020-01586-w

Monteiro LA, Sentelhas PC, Pedra GU (2018) Assessment of NASA/POWER satellite-based weather system for Brazilian conditions and its impact on sugarcane yield simulation. Int J Climatol 38:1571–1581. https://doi.org/10.1002/joc.5282

Ministry of Environment, Science, Technology and Innovation [MESTI] (2013) Ghana national climate change policy. Accra, Ghana. https://www.un-page.org/files/public/ghanaclimatechangepolicy.pdf. Accessed 8 Aug 2023

Naab FZ, Abubakari Z, Ahmed A (2019) The role of climate services in agricultural productivity in Ghana: The perspectives of farmers and institutions. Clim Serv 13:24–32. https://doi.org/10.1016/j.cliser.2019.01.007

Nhemachena C, Hassan R (2007) Micro-level analysis of farmers' adaptation to climate change in Southern Africa. IFPRI Discussion Paper No. 00714. International Food Policy Research Institute, Washington, D.C

Niang I, Ruppel OC, Abdrabo MA, Essel A, Lennard C, Padgham J, Urquhart P (2014) Africa. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1199–1265

Nielsen JØ, D'haen SAL, (2014) Asking about climate change: Reflections on methodology in qualitative climate change research published in Global Environmental Change since 2000. Glob Environ Chang 24:402–409. https://doi.org/10.1016/j.gloenvcha.2013.10.006

Ntim-Amo G, Yin Q, Ankrah EK, Liu Y, Ankrah Twumasi M, Agbenyo W, Xu D, Ansah S, Mazhar R, Gamboc VK (2022) Farm

households' flood risk perception and adoption of flood disaster adaptation strategies in northern Ghana. Int J Disaster Risk Reduction 80:103223. https://doi.org/10.1016/j.ijdrr.2022.103223

Obossou EAR, Chah JM, Anugwa IQ, Reyes-Garcia V (2023) Gender dimensions in the adoption of climate-smart agriculture technologies in response to climate change extremes in Benin. Reg Environ Change 23:93. https://doi.org/10.1007/s10113-023-02085-4

Ochieng J, Kirimi L, Makau J (2017) Adapting to climate variability and change in rural Kenya: farmer perceptions, strategies and climate trends. Nat Resour Forum 41:195–208. https://doi.org/10.1111/1477-8947.12111

Omotoso AB, Letsoalo S, Olagunju KO, Tshwene CS, Omotayo AO (2023) Climate change and variability in sub-Saharan Africa: A systematic review of trends and impacts on agriculture. J Clean Prod 414:137487. https://doi.org/10.1016/j.jclepro.2023.137487

Partey ST, Dakorah AD, Zougmoré RB, Ouédraigo M, Nyasimi M, Nikoi GK, Huyer S (2020) Gender and climate risk management: evidence of climate information use in Ghana. Clim Change 158:61–75. https://doi.org/10.1007/s10584-018-2239-6

Phiri D, Franzel S, Mafongoya P, Jere I, Katanga R, Phiri S (2004) Who is using the new technology? The association of wealth status and gender with the planting of improved tree fallows in Eastern Province. Zambia Agricultural Systems 79(2):131–144. https://doi.org/10.1016/S0308-521X(03)00055-6

Ricart S, Gandolfi C, Castelletti A (2023) Climate change awareness, perceived impacts, and adaptation from farmers' experience and behavior: a triple-loop review. Reg Environ Change 23(82):1–24. https://doi.org/10.1007/s10113-023-02078-3

Richa N, Geiger S (2007) Reflexivity and positionality in feminist fieldwork revisited. In: Tickell A, Sheppard E, Peck J, Barnes T (eds) Politics and Practice in Economic Geography. pp 267–78

Rowhani P, Lobell DB, Linderman M, Ramankutty N (2011) Climate variability and crop production in Tanzania. Agric for Meteorol 151(4):449–460. https://doi.org/10.1016/j.agrformet.2010.12.002

Sadiq MA, Kuwornu JKM, Al-Hassan RM, Alhassan SI (2019) Assessing maize farmers' adaptation strategies to climate change and variability in ghana. Agriculture 9(5):90. https://doi.org/10.3390/agriculture9050090

Sani S, Chalchisa T (2016) Farmers' perception, impact and adaptation strategies to climate change among smallholder farmers in Sub-Saharan Africa: A systematic review. Journal of Resources Development and Management 26:1–8

Saunders M, Lewis P, Thornhill A (2012) Research method for business students, 6th edn, sn Essex: Pearson Education limited

Sertse SF, Khan NA, Shah AA, Liu Y, Naqvi SAA (2021) Farm households' perceptions and adaptation strategies to climate change risks and their determinants: Evidence from Raya Azebo district, Ethiopia. International Journal of Disaster Risk Reduction 60:102255. https://doi.org/10.1016/j.ijdrr.2021.102255

Shah AA, Khan NA, Gong Z, Ahmad I, Naqvi SAA, Ullah W, Karmaoui A (2023) Farmers' perspective towards climate change vulnerability, risk perceptions, and adaptation measures in Khyber Pakhtunkhwa, Pakistan. Int J Environ Sci Technol 20:1421–1438. https://doi.org/10.1007/s13762-022-04077-z

Slovic P (1987) Perception of risk. Science 236(4799):280–285. https://doi.org/10.1126/science.3563507

Smith RA (2018) Risk perception and adaptive responses to climate change and climatic variability in northeastern St. Vincent J Environ Stud Sci 8:73–85. https://doi.org/10.1007/s13412-017-0456-3

Smith EK, Mayer A (2018) A social trap for the climate? Collective action, trust and climate change risk perception in 35 countries. Glob Environ Chang 49:140–153. https://doi.org/10.1016/j.gloenvcha.2018.02.014

Solomon S, Qin D, Manning M, Alley RB, Berntsen T, Bindoff NL, Chen Z, Chidthaisong A, Gregory JM, Hegerl GC, Heimann M, Hewitson B, Hoskins BJ, Joos F, Jouzel J, Kattsov V, Lohmann U, Matsuno T, Molina M, Nicholls N, Overpeck J, Raga G, Ramaswamy V, Ren J, Rusticucci M, Somerville R, Stocker TF, Whetton P, Wood RA, Wratt D (2007) Technical summary. In: Solomon SD, Qin M, Manning, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: The Physical Science Basis." Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Steffen W, Sims J, Walcott J, Laughlin G (2011) Australian agriculture: Coping with dangerous climate change. Reg Environ Change 11(SUPPL. 1):205–214. https://doi.org/10.1007/s10113-010-0178-5

Strauss A, Corbin J (1990) *Basics of qualitative research*: *Grounded theory procedures and techniques*. CA: sage, Newbury Park

Sutcliffe C, Dougill AJ, Quinn CH (2016) Evidence and perceptions of rainfall change in Malawi: Do maize cultivar choices enhance climate change adaptation in sub-Saharan Africa? Reg Environ Change 16:1215–1224. https://doi.org/10.1007/s10113-015-0842-x

Sylla MB, Nikiema PM, Gibba P, Kebe I, Klutse NAB (2016) Climate change over West Africa: Recent trends and future projections. In: Yaro, J., Hesselberg, J. (eds) Adaptation to Climate Change and Variability in Rural West Africa. Springer, Cham. https://doi.org/10.1007/978-3-319-31499-0_3

Tambo JA, Wünscher T (2017) Enhancing resilience to climate shocks through farmer innovation: evidence from northern Ghana. Reg Environ Change 17:1505–1514. https://doi.org/10.1007/s10113-017-1113-9

Tashakkori A, Creswell JW (2007) The new era of mixed methods. J Mixed Methods Res 1(1):3–7. https://doi.org/10.1177/2345678906293042

Tasnim Z, Saha SM, Hossain ME, Khan MA (2023) Perception of and adaptation to climate change: the case of wheat farmers in northwest Bangladesh. Environ Sci Pollut Res 30:32839–32853. https://doi.org/10.1007/s11356-022-24478-4

Tesfahun AA, Chawla AS (2020) Risk perceptions and adaptation strategies of smallholder farmers to climate and variability in North Shoa Zone. Ethiopia Management of Environmental Quality 31(1):254–272. https://doi.org/10.1108/MEQ-04-2019-0076

Tieminie RN, Chia EL, Tieguhong JC, LAwamba F, (2023) Perceptions of climate change and local responses on livelihoods: the case of people around the Mambioko community forest. GeoJournal 88:3969–3984. https://doi.org/10.1007/s10708-023-10849-y

Tirado MC, Hunnes D, Cohen MJ, Lartey A (2015) Climate change and nutrition in Africa. Journal of Hunger & Environmental Nutrition 10(1):22–46. https://doi.org/10.1080/19320248.2014.908447

Wang Z, Li J, Lai C, Wang RY, Chen X, Lian Y (2018) Drying tendency dominating the global grain production area. Glob Food Sec 16:138–149. https://doi.org/10.1016/j.gfs.2018.02.001

Wheeler T, von Braun J (2013) Climate change impacts on global food security. Science 341:508–513. https://doi.org/10.1126/science.1239402

Wheeler SA, Nauges C, Zuo A (2021) How stable are Australian farmers' climate change risk perceptions? New evidence of the feedback loop between risk perceptions and behaviour. Glob Environ Chang 68:102274. https://doi.org/10.1016/j.gloenvcha.2021.102274

Wiegel H, Warner J, Boas I, Lamers M (2021) Safe from what? Understanding environmental non-migration in Chilean Patagonia through ontological security and risk perceptions. Reg Environ Change 21:43. https://doi.org/10.1007/s10113-021-01765-3

Yaddanapudi R, Ashok K, Mishra AK (2022) Compound impact of drought and COVID-19 on agriculture yield in the USA. Science of The Total Environment 807(Part 1):150801. https://doi.org/10.1016/j.scitotenv.2021.150801

Yamba S, Appiah DO, Siaw LP (2019) Smallholder farmers' perceptions and adaptive response to climate variability and climate change in southern rural Ghana. Cogent Soc Sci 5:1. https://doi.org/10.1080/23311886.2019.1646626

Yaro JA (2013) The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. Reg Environ Change 13:1259–1272. https://doi.org/10.1007/s10113-013-0443-5

Yiridomoh GY, Appiah DO, Owusu V, Bonye SZ (2021) Women smallholder farmers off-farm adaptation strategies to climate variability in rural Savannah, Ghana. GeoJournal 86:2367–2385. https://doi.org/10.1007/s10708-020-10191-7

Zagre I, Akinseye FM, Worou ON, Kone M, Faye A (2024) Climate change adaptation strategies among smallholder farmers in Senegal's semi-arid zone: role of socio-economic factors and institutional supports. Front Clim 6:1332196. https://doi.org/10.3389/fclim.2024.1332196

Zha J, Shen C, Li Z, Wu J, Zhao D, Fan W, Sun M, Azorin-Molina C, Deng K (2021) Projected changes in global terrestrial near-surface wind speed in 1.5 ℃ –4.0 ℃ global warming levels. Environ. Res. Lett. 16(11):114016. https://doi.org/10.1088/1748-9326/ac2fdd

Zhang P, Zhang J, Chen M (2017) Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. J Environ Econ Manag 83:8–31. https://doi.org/10.1016/j.jeem.2016.12.001

Zhang Z, Kattel GR, Shang Y, Wang G, Chuai X, Wang Q, Cui X, Miao L (2023) Steady decline in food self-sufficiency in Africa from 1961 to 2018. Reg Environ Change 23:79. https://doi.org/10.1007/s10113-023-02074-7