Bridging Traditional Knowledge and Agricultural Policy in Climate Change Adaptation in Ghana

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Dedication

I dedicate this study to my family for their support in diverse ways. It is specially dedicated to my son, Kwabena, for being my inspiration in all that I do.

Abstract

Climate change has been a global concern over the past decade, prompting the need for coordinated policies at international, national, and local levels to both mitigate its effects and support adaptation. In Africa, smallholder farmers are already adjusting to the environmental changes brought about by climate change. However, the accelerating impacts of human-induced climate change widely documented in numerous studies continue to threaten rain-fed agriculture, worsening hunger and food insecurity in developing countries.

The way smallholder farmers perceive climate change significantly influences their farming practices. Individuals' perceptions of their environment often shape their responses to it, influencing whether they will adopt modern technologies and adaptive techniques aimed at enhancing resilience and coping capacity.

Mainstreaming has been proposed as a strategy for governments to integrate traditional knowledge with scientific approaches in climate change adaptation policies. Increasingly, it is recognized that scientific models alone are insufficient for effective adaptation. Instead, strategies must be tailored to local contexts, promoting the co-production of knowledge from both traditional and scientific sources. This fosters social learning and informs policy actions that can better support the resilience of local systems to climate impacts.

This study aimed to identify and compile the strategies used by crop farmers to adapt to climatic variabilities, with a focus on traditional knowledge, its influence on farming practices, and its integration with scientific methods for policy action.

Specifically, the study sought to assess the extent of farmers' awareness of climate variabilities and to document adaptation strategies rooted in traditional knowledge. It also examined the growing trend of combining traditional and scientific approaches as a regular practice among farmers. Additionally, the study explored efforts to mainstream traditional knowledge into policy at both the district and national levels and identify the barriers to integration and propose potential solutions.

The study covered four districts from two agro-ecological zones in northern Ghana using a mixed-method approach. Data collection included questionnaires, focus group discussions and interviews. Two logistic regression models were used to determine factors influencing

farmers' choices in adopting both traditional and scientific adaptation strategies. In total, 687 participants were engaged, including smallholder farmers, elders, local NGO representatives and policymakers at both local and national level.

A major finding was the seemingly gradual decline in appeal of traditional knowledge, largely due to fast-eroding of nature-based adaptation practices by climate related disruptions rendering them less effective or a lack of awareness of the full benefits of some techniques practiced.

The findings also showed that farmers' perception on changes in weather, status of household head, availability of crop techniques, and access to weather information positively influence farmers' decisions on adaptation practices. Conversely, factors such as the level of education, number of plots, gender, agro-ecological zone, number of crops grown and number of years in farming showed a negative influence on adaptation decisions.

Farmers used mixed cropping, various crop technologies (early-maturing, disease-resistant, pest-resistant, and drought-resistant varieties), and shifting cultivation in crop management practices. For water conservation, techniques such as mulching, mound-making, and bunding were applied. However, bunding and mound-making are gradually becoming less common due to land clearing methods that make their manual constructions unsuitable.

Farmers were also changing their cropping systems, changing planting dates making use of weather information obtained by either traditional prediction or scientific weather (often delivered in local languages via radio or television). The findings also show that increasing input costs and declining yields are making farmers more vulnerable to debt.

Furthermore, the study identified a lack of political will, lack of resources, and limited capacity at the local level as the major barriers to mainstreaming smallholder farmers' traditional knowledge into policy.

The study concludes that mainstreaming traditional knowledge into agricultural policy could enhance the resilience of smallholder farming systems. Policymakers agreed that for adaptation policies to be relevant and content-specific, they must be developed using bottom–up approaches. Although traditional knowledge seems to be dwindling, partly due to the fast rate at which climate impact erodes evidence-based learning locally, it still holds potential as a basis for targeted agro-ecological education and locally relevant climate adaptation strategies.

The study recommends further research into how local policy actors can create opportunities for co-producing knowledge through collaborative partnerships involving research institutions, agricultural extension services, local authorities, and community members. By fostering social learning in these partnerships, local adaptation policies and actions can be better informed, context-specific, and more effective.

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Chapter 1

General Introduction

1.0 Climate change and Agriculture

Agricultural systems are impacted drastically by climate change as it affects both plant and animal health (Pereira, 2017), making production highly sensitive to changing weather and climate. According to IPCC (2021), different types of climate extremes are predicted to increase and become more regular, affecting various areas of the world due to the changing climate. These extreme occurrences, for instance droughts, increased temperature, and heat waves, can negatively influence agricultural production and have consequences for the livelihoods and food security of communities. Bailey et al. (2015) and Puma et al. (2015) stated that not only regions directly facing the extreme event will be affected, but also regions in other parts of the world may suffer from indirect effects such as reduced exports of agricultural products and higher food prices. Africa is projected to be one of the continents to have the most impact from climate change for two reasons: its geographical features, which have most of its lands across the warming tropics, and the inadequate human, social and economic capability to adapt to the impacts of climate change (Leal Filho et al., 2015). Agriculture also retains a dual identity globally - as an industry in developed countries and a way of life in developing countries (Lal, 2021). Agriculture, therefore, must be integrated into any universal agenda on climate change mitigation and adaptation, since under the setting of climate change, agriculture is an ecological activity, not an economic activity. However, temperature rises caused by human-induced climate change have been recorded across Africa, with several places warming faster than the global average. However, uncertainty of detected rainfall tends to occur in the African region (Ranasinghe et al., 2021). According to FAO and ECA (2018), these changing climates are significant and raising concern for food security and nutrition in Africa, particularly in agriculturally dependent countries. Reduced precipitation and increased temperatures already have a detrimental impact on staple food crop production and on modifying farming systems. According to the IPCC (2022), a 2°C temperature rise will cause yield reductions in staple crop production across most of Africa compared to 2005 yields (e.g., 20–40 % decline in West African maize yields), even when adaptation options and increasing CO_2 emissions are considered. Also, the impact of climate change has decreased agricultural production in Africa by 34 % since 1961, more than any other region. Maize and wheat yields have decreased by 5.8 % and 2.3 %, respectively, in sub-Saharan Africa since 1974, causing smallholder farmers and pastoralists to believe climate has changed, and leading more than two-thirds of Africans to believe that climate conditions for agricultural output have deteriorated over the last decade (Trisos et al., 2022).

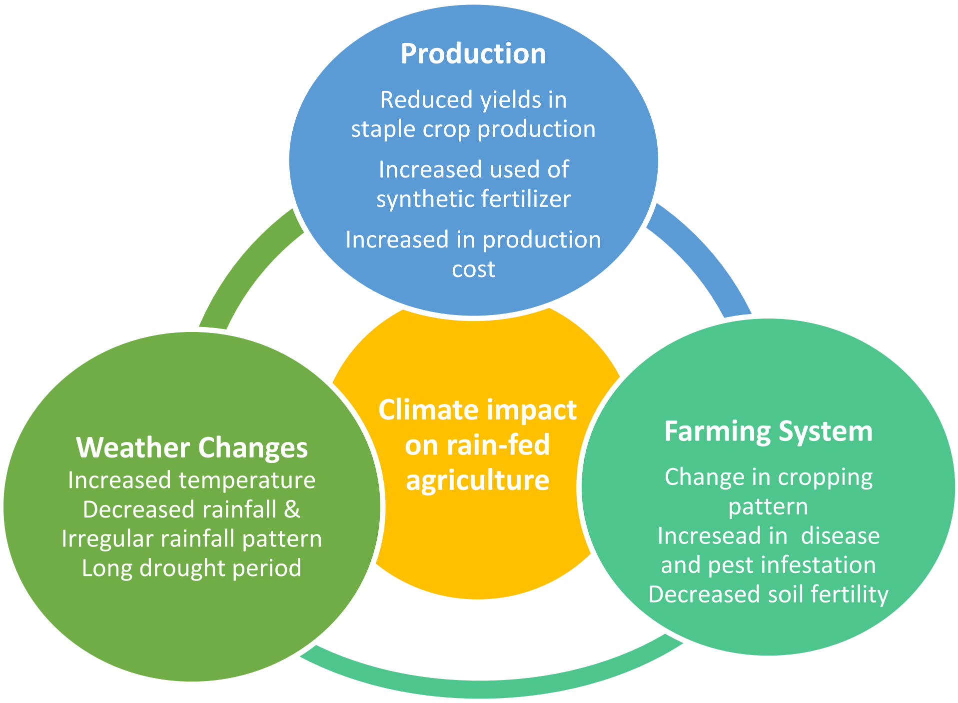


Figure 1.1: Showing various aspects of climate change's impact on rain-fed agriculture by human-made climate change.

Hotter temperatures and high humidity have been linked to maize contamination by moulds and fungi, as evidenced along the maize-poultry value chain in Nigeria (Liverpool-Tasie et al., 2019). Africans are disproportionately engaged in climate-vulnerable sectors: agriculture employs around 60% of the sub-Saharan workforce, and 95 % of farmland is rain-fed. Climate hazards pose a threat to the livelihoods of impoverished farming families in rural Africa (Trisos et al., 2022). Extreme weather occurrences have also contributed to increased acute food insecurity and malnutrition among millions of Africans in need of humanitarian help (Gebremeskel-Haile et al., 2019). Between 2015 and 2019, an estimated 45.1 million people in the Horn of Africa and 62 million in eastern and southern Africa required humanitarian assistance due to climate-related food shortages. Children and pregnant women are disproportionately affected in terms of health and nutrition (Gebremeskel-Haile et al., 2019). Furthermore, climate change will lead to food insecurity for 71 million people in the world by 2050, with more than half of them living in sub-Saharan Africa (FAO & ECA, 2018).

1.1 Smallholder farming and climate change impact

Farmers are at the forefront of attempts to reduce climate change's harmful effects on food systems. While changes and shocks to global and regional food systems will touch all individuals in some way, food producers will initially endure most of the consequences, especially smallholder producers from the developing world. Crop failures are becoming more likely as global temperatures rise and erratic or extreme weather events spread more frequently across regions (IPCC, 2014a; FAO, 2017). These events can lead to additional land management crises through soil erosion, flooding, and drought, all of which can make food production more difficult or impossible (IPCC, 2014b). These effects already affect producers' ability to distribute and sell food and will have a detrimental impact on global food security (FAO, 2016; Ingram et al., 2016). The livelihoods of farmers are therefore at risk worldwide: climate change is expected to increase net poverty, especially in rural regions where agricultural production is economically essential (Hallegatte et al., 2016).

1.2 Traditional knowledge

1.2.1 Conceptual definition of traditional knowledge

The knowledge generated and shared by indigenes, or local people, has been classified and defined in several ways depending on the source and purpose of the definition. For instance, in the field of sustainable development, it is referred to as indigenous technical knowledge, traditional environmental knowledge, rural knowledge and farmer’s or pastoralist’s knowledge (Warren, 1991). Johnson (1992) defines Indigenous knowledge to be a body of knowledge built up by a group of people through generations of living in close contact with nature. Also, science education research literature often identifies indigenous knowledge by such phrases as: traditional knowledge (ICSU, 2002), traditional wisdom (George, 1999b), traditional ecological knowledge (Snively & Corsiglia, 2001). Furthermore, native science (Cajete, 2000b), Aboriginal science (Aikenhead, 2006), Mäori science (McKinley, 1996), and Yupiaq science (Kawagley, 1995). For instance, widely used term, indigenous knowledge (IK), emphasizes attachment to place and establishes a link with indigenous peoples (Nakashima

& Rogue, 2002). Some practitioners argue that such identification based on location was too narrow excluding people who may have lived in an area for a long period of time but are not the original inhabitants. They expanded the definition as knowledge possessed by any group living off the land in a particular area for a long period of time (Langill, 1999), a broader concept referred to as local knowledge. Various scientific, political, and social considerations make it all but impossible for a single term to suit all settings required for the defining the concept of indigenous knowledge without any shortcomings (Nakashima & Rogue, 2002; IPBES 2021; Yeleliere et al., 2022b). This has led to practitioners using the terms interchangeably in the field (Langill, 1999; Aikenhead & Ogawa, 2007). However, this study adopts to use the term traditional knowledge (TK) as found in science education literature (UNESCO-ICSU, 2002) and defines it as a cumulative body of knowledge, expertise, practices, and representations maintained and developed by peoples with extended histories of interaction with the natural environment. Encompassing understandings, interpretations, and meanings of cultural complex such as language, naming and classification systems, resource use practices, ritual, spirituality, and worldview (UNESCO- ICSU, 2002). The study adopts the definition for its capture of elements as expertise and practices based for which it aims to profile climate adaptation by smallholder farmers. However, other terms used in cited literature will be maintained in the study (Bohensky & Maru, 2011)

1.2.2 Traditional knowledge and climate change adaptation

Husbandry and agriculture are two of the earliest ways humans have interacted with the environment and managed ecosystem services (Fisher et al., 2009). Traditional agriculture is the result of thousands of years of experiences supplied by local agricultural traditions (Pulido & Bocco, 2003). Traditional farming techniques had an important influence on the development of agricultural science knowledge (Sandor & Furbee, 1996; Kerr & Sanghi, 1991). For ages, they have fed a sizeable population and continue to do so in various parts of the world (Koohafkan & Altieri, 2010). Traditional societies have relied significantly on their own Indigenous knowledge systems to study the environment and deal with natural risks throughout history. According to Pareek and Trivedi (2011), the knowledge gained from observation and research from accumulated experiences and has been down from generation to generation. In recent years, it has been acknowledged that scientific models that ignore local people’s perceptions of climate change are inappropriate, as local knowledge can be useful in designing policies to deal with the negative impacts of climate change (Byg & Salick, 2009; Weber, 2010). Meanwhile, traditional agriculture practices have received increased attention globally, as a climate-smart approach to conservation and sustainability of local environment and livelihoods (Terdoo & Adekola, 2014; Srivastava et al., 2016; Partey et al., 2018) while policy decisions based solely on scientific models may not reflect the concerns and priorities of local people. In support of this, Moonga and Chitambo (2010), Saitabau (2014) and Mapfumo et al. (2015) argued that understanding and incorporating traditional knowledge have become increasingly topical and have been embraced by academics and development practitioners as essential to addressing the multiple livelihood challenges faced by rural communities in developing countries. This serves as the foundation for locally led adaptation plans that can move beyond the planning stage and begin to be implemented. Several scholars have explored local farmers' experiences with climate change and variability, considering the emerging understanding of the relevance of traditional knowledge in dealing with climate change (West et al., 2008; Yaro, 2013). Ingram et al. (2002), for example, investigated the geographical differences in farmers' perceptions of climate change and their capacity to use weather predictions in Burkina Faso. According to Roncoli et al. (2002), farmers in the Sahel use several local indicators to forecast rainfall and adjust their resource management techniques appropriately. West et al. (2008) investigated local perceptions of rainfall patterns in Burkina Faso, while Meze-Hausken (2004) compared local farmers' views of climatic variability with rainfall variability observations in northern Ethiopia. Yaro (2013) investigated climate change perspectives among small traditional and contemporary commercial farmers in southern Ghana. He showed that small farmers explained their local knowledge and experiences for observed climatic changes, but modern commercial farmers understood climate science better. He also stated that specialised strategies are required for climate profiling (modelling) in agricultural investment and efforts. Moreover, some studies have focused on the factors that impact farmers' decisions to adapt to climate change at the farm level (Roncoli et al., 2002; Ziervogel et al., 2005; Vogel & O'Brien, 2006). These studies investigate farmers' perspectives, information utilisation, and other aspects impacting decision-making. However, despite the vital importance, the contrasts and synergies between the traditional knowledge used to manage climate risks and the seasonal climate projections are seldom documented (Letson et al., 2001; Broad et al., 2002; Patt & Gwata, 2002; Vogel & O'Brien, 2006). This lack of focus has made it harder to harmonise this diverse knowledge base for inclusion into policy. However, according to Yamba et al. (2019), policy must allow and capitalise on traditional knowledge to achieve long-term climate action.

1.2.3 Limitation of traditional knowledge

Like all knowledge sources, traditional knowledge has limitations that need to be considered in its application to be able to achieve the maximum benefits in climate change adaptation. Traditional knowledge is created within a worldview that incorporates both physical and spiritual components. This makes it difficult to harmonize with western knowledge based on entirely different worldviews (LaDuke, 1994:146). Also, since traditional knowledge is created and transferred orally in local languages, transferring it into another language often results in either misinterpretation or change of the meaning. Furthermore, the mode of the transfer also leads to breaching of cultural norms by knowledge holders (Cronon, 1996).

Specifically in Africa, limitations of use of Africa traditional knowledge in climate adaptation recorded in studies from various countries and across ecosystems show negative effect by several factors. For instance, Seaman et al. (2014) and Mafongoya et al. (2017) recorded that local farmers depending on traditional systems for livelihoods are of the view that African governments do not support or promote traditional knowledge in policy development while most governmental agricultural extension officers consider traditional knowledge to be unscientific and unreliable (Mafongoya et al., 2017).

Also, due to undocumented nature of traditional knowledge in Africa in addition to it inadequately being captured in literature, African governments often do not recognise or include it in adaptation planning (Ford et al., 2016; IPCC, 2019b). The possibility of the extinction of traditional knowledge is also cited as a limitation to its use since it is passed down orally or demonstrated from generation to generation, being preserved mostly in the memories of the elderly. Memory gaps or refusal of the holders to pass it on to the next generation may lead to the disappearance of the knowledge (Rankoana, 2016a).

Additionally, IIED (2015) recorded that how traditional knowledge is transferred, accessed, and shared is uneven making it difficult for official channels to utilise it easily when required in policy development.

Urbanisation is another factor identified as a threat to traditional knowledge according to Fernández-Llamazares et al. (2015), asserting that due to limited use of it by migrant rural dwellers to urban areas for greener pastures, the knowledge is lost with time.

Also, the lasting effect of colonisation on most African societies where the African indigenous ways of knowing were devalued and marginalised for western culture and knowledge (Bolden et al., 2018) limiting the use of traditional knowledge amidst concerns about the effectiveness of both traditional knowledge indicator and related adaptation responses by communities in predicting and adapting to weather events under future climate conditions (Speranza et al., 2009; Shaffer, 2014; Hooli, 2016).

1.3 Defining Scientific Knowledge (SK)

"Science" comes from the Latin word "Scientia," meaning "knowledge." It refers to progressive compilation of knowledge and practices, emerging as scientific procedures derived from established theories or research processes, encompassing validity and reliability (Turnbull, 1997, Fazey et al., 2004, Pullin & Knight 2001). Additionally, to Alexander et al. (2011), science is made up of instrumental recordings or statistically examined files that are formed from precise features of dependent and independent variables, regularly assessed to demonstrate a suitable degree of validity and reliability. The US National Academies Press (2019) defines science as an approach to inquiry aimed at posing questions about the world and reaching well-founded conclusions through collaborative efforts.

Scientific knowledge, therefore, refers to a methodically and empirically supported comprehension of the natural world and the laws governing it, achieved through rigorous scientific research, reflections, testing, and examinations. However, evidence produced is determined by the philosophical and epistemological stance of the person or organization, or the method by which the knowledge was obtained (Turnbull, 1997, Fazey et al., 2004, Pullin & Knight, 2001). This study defines scientific knowledge as knowledge generated analytically using proven procedures and ideas, such as scientific method (Raymond et al., 2010).

Thus, the study defines traditional practices as techniques or knowhow developed by peoples with extended histories of interaction with the natural environment while scientific practices include technologies developed with modern science procedures and methods.

1.4 Mainstreaming of Traditional knowledge into Policy

UNDP-UNEP (2021) described mainstreaming climate change adaptation as the repeated process of adding deliberations of climate change adaptation into policymaking, budgeting implementation, and monitoring processes at national, regional, and local levels. Mainstreaming is frequently related to the practice of considering potential climate change consequences when making investment or development aid choices. In the framing of mainstreaming framework, Wamsler and Pauliet (2016) enlisted seven strategic levels (activities) namely:

i. Add-on mainstreaming – special initiatives are introduced into the organisation's primary activities
ii. Programmatic mainstreaming – modification of sector work to accommodate climate actions
iii. Managerial mainstreaming – alterations to supervisory and working structures
iv. Intra-organisational mainstreaming (internal cooperation among departments)
v. Inter-organisational mainstreaming (cooperation and inter-connection with other departments)
vi. Regulatory mainstreaming – changes in formal and informal planning procedures, rules, and legislation that contribute to adaptive integration.
vii. Directed mainstreaming – giving the highest priority to focus on features related to climate adaptation

Although the framework may be used to whole adaptation or certain components including other cross-cutting themes such as climate change mitigation, it is most suited to total adaptation. However, Wamsler and Brink (2014) stated that applying it to adaptation will require a comprehensive technique for climate risk reduction. Runhaar et al. (2018), in their review of mainstreaming initiatives across developed and developing countries, observed that while many sectoral policy documents and plans mentioned mainstreaming, fewer than half included specific programmes or actions for implementation. The factors causing the implementation gap were the foremost is that mainstreaming efforts involve a large set of actors, institutions, and processes. Secondly, is that the moving from planning to implementation requires overcoming multiple resource, institutional, and capability challenges (Mimura et al., 2014; Gogoi et al., 2017). Thirdly, there is lack of sustained political commitment and effective cooperation and coordination among key stakeholders. Lastly, the absence of clear mandates, competing political interests, and inappropriate organisational structures and practices (Runhaar et al., 2018). But access to information and expertise are not significant barriers to mainstreaming implementation (Runhaar et al., 2018).

1.5 Resilience

Resilience is the ability of a system to endure shocks while maintaining its core functions, structure, feedback mechanisms, and overall identity (Walker et al. 2006). However, the resilience concept proposed by Holling (1973:17) looked at resilience in two ways 'engineering' and 'ecology', referring to the ability of an ecosystem to return to a state of stability after a disturbance, or to absorb changes 'and still persist'. Since then, resilience thinking has expanded from its original, restrictive definition to include the capacity to recover or reestablish equilibrium after a disruption, or "engineering resilience" to a more comprehensive theory that emphasizes flexibility and transformability as essential components (Folke et al., 2010). Defining resilience depends on the field and purpose for its use. For instance, Adger (2000) defines social resilience as the ability of groups or communities to cope with external shocks and disturbances because of social, political, and environmental change. But the ability of ecosystems to sustain themselves in the face of disruption is known as ecological resilience, linking ecological and social resilience. This connection between ecological and social resilience is obvious especially for communities or social groupings who depend on natural resources for their way of life as do most rural communities in developing countries. Adger, (2000) and Walker and Cooper (2011) indicated ecological resilience places more focus on systemic change or adjusting to a new normal that would be less susceptible to hazards developed from Hollings (1973) definition of 'ecological resilience'. Folke et al. (2010) acknowledged the possibility of dynamic change across scales as a perspective from social-ecological systems emphasizing the interaction of creativity, learning, and adaptability in producing system properties like resilience. This gives the possibility of restructuring of systems that point out "bouncing forward" or evolving to a less vulnerable state rather than merely "bouncing back" to a pre-shock condition (Maguire & Cartwright, 2008; Shaw & Theobald, 2011). From a political standpoint, resilience is a way to control uncertainty (expected or unexpected future risks or shocks) in a system. Climate change resilience is the ability to anticipate, adapt to, and recover from the effects of extreme weather events with the least amount of harm to the environment, the economy, and society (IPCC, 2012). Also, DFID (2013) indicated that the ability of a system and its constituent elements to adapt to longer-term climate changes, including transformative change and tipping points, is included in the concept of climate resilience. However, some argued that resilience is not a universally accepted term, despite its wide range of applications and contexts. Stating for instance that even in single-geography fields like disaster risk reduction, climate change adaptation, humanitarian aid, spatial planning, governments, and organizations also have different perspectives on resilience, seeing it as a process, a state, or a quality (Lewis & Kelman, 2010; Davoudi, 2012; Levine et al., 2012; Alexander, 2013).

Conversely, Walker et al. (2004) asserted that transformability is a related idea that deals with what to do when a change into an undesirable regime is either unavoidable or has already happened and cannot be reversed, resulting in a new system regime. Béné et al. (2012) demonstrated that a system becomes resilient only after surviving change persistently, with incremental adjustments in the system until eventual change, resulting in a new system that has the capacity to either absorb or withstand the impact of change.

However, there is disagreement over the mechanisms that produce transformations (Smith et al., 2005). Some people believe that transformation happens naturally because of small-scale, well-thought-out interventions undertaken by (usually policy) actors (Schot & Steinmueller, 2018), while others believe that change is an effect of societal mobilization and significant political-economic forces (Stirling, 2015). In other situations, transformation is not caused by humans, but rather by external biophysical processes like climate change, which are outside the control of any individual or group even though they may be anthropogenic in origin (Kates et al., 2012). Thus, resilience building of a system regime requires conscious efforts from diverse actors to secure sustainability in a stressed environment (Ungar, 2018). Scoones et al. (2020) therefore proposed three approaches: systemic, structural and enabling approaches.

Although, in the scientific community working on climate change uses resilience extensively (Füssel, 2007), there exists a disagreement over what resilience means, which can occasionally cause confusion because of the lack of a precise definition (O'Brien et al., 2005; Gallopin, 2006; Janssen & Ostrom, 2006; DFID, 2013; Lindoso, 2017)). There is considerable debate over how the concepts of vulnerability, resilience, adaptation, and adaptive capacity are interconnected (Cutter et al., 2008; Edmonds et al., 2020; Yavuz et al., 2020). While some scholars such as Folke et al. (2002), Villagran de León (2006), and Proag (2014) view resilience as the inverse of vulnerability, implying a reduction in risk, others like Klein et al. (2003) interpret resilience more positively, as an enhancement of a system's ability to cope and adapt. Therefore, a high level of vulnerability to climate change typically indicates low resilience to its impacts (Villagran de León, 2006; Shah et al., 2018). Some scholars, such as McEntire (2001), Turner et al. (2003), Pelling (2003), and Hoterova (2020), view resilience as a component embedded within the broader concept of vulnerability reflecting an inclusive relationship. Resilience is also seen as part of adaptive capacity, which refers to a system's ability to modify its characteristics or behaviour to better cope with current or future external stresses (Adger et al., 2004). Consequently, numerous factors can influence the resilience, adaptability, and vulnerability of an agricultural system.

Agro-ecosystem resilience and social resilience are closely related, especially for social groups or communities that depend on ecological and environmental resources for their means of livelihood (FAO, 2007). For instance, smallholder farmers are more vulnerable to sudden and unpredictable changes in temperature and rainfall patterns, which exacerbate rural poverty (AGRA, 2014; Kansiime & Mastenbroek, 2016; Fahad & Wang, 2020). As much as resilience can be an indicator of a person's capacity to handle challenging or stressful circumstances, it depends on group efforts, particularly on how farming communities effectively build their social and natural capital based on social elements, institutions, politics, power, and local contexts (Brown, 2014; Westley et al., 2011). But according to Altieri et al. (2013), farmers and their systems are susceptible to climate shocks because of these capitals. Thus, strengthening and expanding social networks at the local and regional levels can lessen social vulnerability and boost the resilience of agro-ecosystems.

On the other hand, resilience can be either "good" or "bad," and understanding it without political-economic or cultural theory can be challenging. Understanding a system's resilience does not necessarily indicate its socially preferred state, while a resource's specific resilience may lead to a loss of general resilience. For instance, a study by Seccombe (2004) of a market liberalization and the privatization policy of mangroves at one location in northern Vietnam undermine environmental as well as societal resilience. This loss of resilience was associated with negative repercussions on livelihoods, and in the context of the institutions of common property management, and damage of collective institutional resilience. Ifejika (2010) asserted that resilience factors can make people more susceptible to unpredictability and climate change. For example, cattle sold for profit, raising animals can be a resilient tactic without drought. However, keeping livestock during a drought makes farmers more susceptible to the effects of climate change due to risks. Also, O'Hara et al. (2016) argued that while insurance is often discussed within resilience frameworks, it is maladaptive, since the system is set up to enforce existing vulnerabilities and exposures by returning to the status quo, rather than encouraging adaptive and transformative behaviour that could reduce future risks.

Policies for climate resilience building can be perceived as either beneficial or detrimental by different segments of society, as they often involve trade-offs and incremental adjustments to existing system regimes that may lead to diverse social impacts. The notion of desirability can be viewed from social (Scheffer et al., 2000, 2002), ecological (Walker & Meyers, 2004), or economic (Carpenter & Brock, 2004) perspectives. Consequently, developing resilience-building policies must involve all stakeholders to ensure inclusivity and fairness.

White and O'Hara (2014) caution against the uncritical use of the term "resilience" within policy discussions, whether by politicians, policymakers, ecologists, or planners, emphasizing the importance of clarifying the point of reference and justifying why resilience is considered a desirable policy goal. To effectively enhance community resilience and reduce vulnerability, local institutions rooted in traditional knowledge should collaborate with state-level institutions in policy development and implementation (Ingty, 2017). Additionally, robust networks are essential for effective coordination among all stakeholders addressing structural inequalities within society (Negi et al., 2017; Son et al., 2020; Sakapaji, 2022). Social policies that strengthen families, enhance their capabilities, and improve their ability to cope with challenging climatic conditions are also crucial (Seccombe, 2004).

1.6 Sustainable Livelihood

Livelihood interventions have been promoted in development cycles especially in development and poverty alleviation rural areas using various conceptualizations by different researchers and scholars due to their multi-dimensional and complex nature (Odoom et al., 2022). The livelihood approach has been assessed to have relevance to the achievements of

SDGs 1, 2, 4 and 12 that target improvement of livelihoods. In conceptualisation of livelihood, Ellis (2000) asserted that the meaning is often ambiguous due to the different definitions within diverse context. Whereas Scoones (2009) declared that livelihood as a mobile and flexible term can be assigned to all sorts of words to build whole areas of development analysis and practice. Chambers and Conway (1992) indicate in their popular definition that competences, assets (material and social resources) and actions are means of living. Similarly, livelihood is the consolidation of resources people utilize and undertake actions to make a living (DFID, 1999). Both definitions acknowledge that livelihood refers to the mixing of resources coupled with people's actions with the ultimate goal of earning a living (Serrat 2008).

However, "livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets without undermining the natural resource base" (Scoones 2009: 175). According to DFID (2000), sustainable livelihood is the adeptness to cope with various stresses and impacts while recovering independently, without harming natural resources, to preserve and enhance households' current and future capacities and assets.

But to Scoones (2009), livelihood relates to settings, occupations, social differences, directions, dynamic outlines and much more which are created by how individuals, households, and communities use their capabilities and means of living to secure food, income, and assets (Mclean, 2015). Thus, livelihood strategies are dependent on individuals, household, and communities' access to livelihood capitals stored or accumulated or exchanged and put to work to generate flow of income, means of livelihoods or other benefits (Rakodi, 1999). In using these resources, a household or community may adopt diverse tactics to meet livelihood aspirations and resulting outcomes and make a pathway for livelihood over time (Matita et al., 2021). For instance, smallholder farming households engage in agricultural intensification to develop routes that change their livelihood outcomes in making a smallholder livelihood system (Dou et al., 2020). This is directly tied to the use of small-scale agriculture and forestry resources, amidst local environmental and institutional resources. They face new challenges because of rapid changes in an array of socio-economic, political, and ecological conditions. Massive population growth as recorded in developing countries as well as land use changes and land degradation respectively have led to dramatic socio-ecological changes (Kiteme et al., 2008). Livelihoods are further exposed to economic liberalization, new governance structures, food insecurity and ethnic conflicts, among others. Also, the expected increasing frequency of droughts and floods (IPCC, 2007) due to changing climate poses new threats to agrarian livelihoods. For instance, reduction in rainfall, variation in rainfall distribution, drought and variation in temperatures have affected livelihood assets of rural communities due to their influences on farmlands, biodiversity and wildlife that are the basic capital that rural people depend on for their livelihood (Amisah, et al. 2009).

The livelihood approach has been criticized for its inability to address global markets and political shifts, weak links to governance and development debates, insufficient attention to large-scale environmental changes and failure to incorporate scientific analysis of climate-related impacts on economies and livelihood resilience (Scoons, 2009; Biggs et al., 2014, 2015; Horsely, 2015).

1.7 Coproduction of Knowledge

Knowledge coproduction is proposed as a methodology to address the significant gap between available knowledge and its application in societal actions, helping to accelerate preparedness and solutions for climate and sustainability challenges (Norström et al., 2020). A useful method in answering environmental issues may result in an increase in community adaptive capacity in the face of climate change (Church et al., 2022). According to Armitage et al. (2011) and Norström et al. (2020), knowledge co-production is defined as an ongoing, collaborative process that combines diverse sources and types of knowledge through partnerships to foster a shared understanding of a problem and its potential solutions while Wyborn et al. (2019) set coproduction as procedures that repetitively connect ways of knowing and acting including ideas, norms, practices, and discourses leading to mutual strengthening and reciprocal transformation of societal outcomes.

These definitions set knowledge coproduction to encompass research across groups which traditionally would be labelled as users or producers, working together to produce, distribute, and implement research findings (Durose et al., 2017). For instance, knowledge coproduction in policy requires the use of diverse actors with different knowledge bases, worldviews, norms, and practices for policy formulation especially in climate action. Potentially to spread ideas and innovation to local peers in developing locally appropriate practice in ways that reflect citizen preferences for small-scale, informal activities (Durose et al., 2017).

Also, Miller and Wyborn (2018) argued that coproduction must go beyond stakeholder engagement by scientist to the more deliberate design of societal transitions such as shifting institutional arrangements that govern relationships between knowledge and power, science and society, and state and citizens. Thus, coproduction contains many aspirations to involve diverse participants to produce multiple outcomes, including new knowledge, new ways of integrating knowledge into decision making and action, importantly new outcomes.

Yet, just as stakeholders in coproduction are diverse, so too are the approaches to the coproduction process, with no one-size-fits-all solution (Sillitoe, 2017; Abu, Reed, & Jardine, 2019; Buell et al., 2020). For instance, Teenage et al. (2014), noted three approaches; knowledge integration, cross-fertilization or co-existence and co-production practiced in combining traditional knowledge and western science knowledge in climate actions in literature. However, Chapman and Schott (2020), Henri et al. (2020), Latulippe and Klenk (2020), Alexander et al. (2021), Cooke et al. (2021) and Korhonen-Kurki (2022), attested that knowledge coproduction had a push upfront due to its underpinning aim of contributing to multiple sources of knowledge, ways of knowing and perspectives from different user groups in co-creating knowledge (Cooke et al., 2021). Hakkarainen et al. (2021) endorsed the adoption of coproduction, along other terms for similar trans-disciplinary and participatory research approaches, due to its widespread use in sustainability science literature, where its emphasis on solutions in knowledge production is a key factor while Weaver (2022) established shortcomings and insufficiencies in knowledge integration and co-existence approaches. For instance, Obermeister (2017) observed that in putting the three approaches on a scale from weak to strong, knowledge integration is often criticised for asymmetric power dynamics on the weak end leading to rejection of other knowledge sources (traditional knowledge) often, annexation, manipulative extraction of knowledge and cultural destruction (Tengö et al., 2014; Löfmarck & Lidskog, 2017; Mazzocchi, 2018; Chapman & Schott, 2020; Latulippe & Klenk, 2020). Coexistence, on the other hand, is between the two ends of the scale placing traditional and western knowledge in close proximity with, and parallel to, one another. Whereas at the extreme end of the scale knowledge coproduction promises "an active partaking of diverse knowledge systems at all stages of knowledge generation"

(Obermeister 2017:81) through to practical knowledge application (Tengö et al., 2014; Klenk et al., 2017; Cooke et al., 2020). Example is the incorporation of traditional techniques/practices used by smallholder farmers in climate change policy formulation.

Furthermore, Jagannathan et al. (2020) observed the use of outcome-oriented, practical and pragmatic, as well as empowering and transformative used as variant for coproduction but Wyborn et al. (2019:319) argued that "both theory and practice of knowledge coproduction must move beyond stakeholder engagement to a more deliberate design of societal transitions, whether the aim is to gain more accurate data, usable knowledge or social transformations."

Knowledge coproduction has been criticized for its inability to overcome persistent power-inequalities, especially so when conventional powerholders would want to hold control over the collaboration to continue to define and frame problems without other actors' input (Pohl et al., 2010; Wyborn et al., 2019; Cooke et al., 2021). Also, co-production is time and resource intensive (cost of funding; stakeholder fatigue) particularly as it takes time and investment to engage and maintain relationships with sustained trust and readiness to engage (Cooke et al., 2021; Korhonen-Kurki et al., 2022; Howarth et al., 2022).

1.8 Statement of Research Problem

The deterioration of environmental conditions due to climate change has become a global issue requiring coordinated international responses. Studies show that Africa is particularly vulnerable, largely because of its limited adaptive capacity and heavy reliance on subsistence agriculture (UNFCCC, 2011; Tubiello et al., 2002). In Ghana, agriculture is predominantly small-scale, with about 90% of farms under two hectares in size (MoFA, 2016). This sector is further challenged by rising temperatures, prolonged droughts, and shortened rainy seasons. Projections indicate that the average base year temperature of 1.0°C could rise by 0.6°C by 2020 and up to 4.0°C by 2080, with rainfall expected to decline by 1.1% to 20.5% during the same period across all agro-ecological zones (MESTI, 2015).

Given the diverse environmental conditions in Ghana's five agro-ecological zones (MoFA, 2016), the effects of climate change will vary across regions, requiring localized adaptation by farmers to maintain their livelihoods. Common adaptation strategies include irrigation, use of improved seed varieties, crop and farm diversification, adjusted planting dates, and alternative income-generating activities (Uddin et al., 2014; Ndamani & Watanabe, 2016; Ansah & Siaw, 2017). However, these efforts are often hindered by financial, social, cultural, and institutional barriers (Jones & Boyd, 2011; Pasquini et al., 2013), contributing to a generally low adoption rate of agricultural innovations across sub-Saharan Africa (Meijer et al., 2015).

Although Ghana, like other Kyoto Protocol signatories, has developed climate action plans, the persistently low adoption of agricultural innovations highlights the need for strategies that directly address the barriers faced by smallholder farmers. Research that captures local knowledge and attitudes toward agricultural innovations can inform the development of context-specific strategies, increase adoption and improve sustainability for rural communities (Meijer et al., 2015).

Because the effectiveness of adaptation strategies varies by agro-ecological zone, policies must be tailored accordingly and integrate traditional knowledge. This approach helps avoid introducing unsuitable technologies or top-down interventions that are difficult to promote at the local level. Integrating scientific and traditional knowledge has been widely advocated to strengthen climate resilience in vulnerable communities, especially in the Global South. However, while the Global North has made strides in combining these knowledge systems, such integration is less prevalent in the Global South (Boillat & Berkes, 2013; Kim et al., 2017).

Although there is a growing body of research on traditional knowledge in Africa, most studies have focused on smallholder farmers' perceptions, vulnerabilities, adaptation strategies, and the role of traditional knowledge (Gyampoh et al., 2009; Naess, 2013; Boafo et al., 2016; Ubisi et al., 2019; Sullo et al., 2020). While other research has examined the factors influencing adaptation choices and mainstreaming traditional knowledge into policy (Atanga et al., 2017; Basdew et al., 2017; Mantyka-Pringle et al., 2019; Yeleliere et al., 2023). However, these studies often exclude the perspectives of policy actors at both local and national levels, despite their crucial role in shaping adaptation policies.

Recent findings indicate that in Ghana, policymakers often undervalue the role of traditional knowledge in climate action (Leal Filho et al., 2021), leading to its limited inclusion in policy frameworks, especially in agriculture and rural development (Yeleliere et al., 2023). This points to a significant gap in literature. Bridging the knowledge and experiences of smallholder farmers with the perspectives of policymakers could enhance the relevance and impact of adaptation policies, encouraging stronger local engagement and more effective climate action.

Thus, the goal of this study is to identify and compile the traditional knowledge used by crop farmers specifically in planning for adaptation to climatic variations, its influence on farming activities, and how it is used in relation to‘ scientific ’methods.

Specifically, this study aims to:

1. Determine the farmer-level information on the degree of observed and perceived climate changes and extreme climate variations.
2. Identify manifested climate impacts on farming practices in two selected agro-ecological zones.
3. Determine the various adaptation strategies used by farmers.
4. Outline the traditional knowledge used and how it augments the use of scientific methods in adaptation to climate variabilities.
5. Explore how this knowledge could best be mainstreamed into policy.

1.9 Research Questions

The research questions are:

a. To what extent are local farmers aware of climate variations in their agricultural zone?
b. What strategies are farmers employing informed by traditional knowledge to adapt to these climate variations?
c. Which combined strategies have become a regular practice used by farmers?
d. Is there a plan to mainstream and institute traditional knowledge in policy at both the district and national levels? If not, what are the barriers to this and how could they be overcome?

1.10 Rationale

The expected societal impacts are:

i. Stimulate more research into various traditional knowledge structures used by subsistence crop farmers in selecting adaptation strategies to combat climate change effects locally to enable mainstreaming into policy.
ii. Initiate further research by both academics and non-governmental organisations as to why the traditional knowledge used in farming practices is successful or not.
iii. Enable local agricultural extension officers to tailor their interventions from an informed position.
iv. Provide a source of information for policy makers in their bid to bridge the gap between traditional knowledge and scientific methods in policy formulation.

1.11 Conceptual framework

Smallholder farmers 'perception of changes in their environment is recorded in literature to influence how they interpret the effects of the changes on their farming activities and livelihood in general. Experience-based perception forms the basis for planning and strategizing for coping and adapting to climate change and extreme weather conditions. Other factors such as media information on climate change and extreme weather, access to weather information and access to extension services could result in changes in perceived or observed situations leading to changes in livelihood choices.

Changing climate conditions have long been part of smallholder farming requiring continuous incremental adjustments to farming practices to adapt to these changes resulting in accumulation of knowledge and expertise over time. The accumulation and transmission of social norms, belief systems and tactical knowledge through social learning forms the traditional knowledge system transferred orally generationally. This orally transferring of knowledge and hand-on practices enable farming communities to undertake incremental adjustments to cope with changing environment and climate. This is expected to lead to the transformation of the system's ability to adapt to the changes. However, the era of human-induced climate change has led to rapid environmental changes such that farmers have been adopting science and traditional technologies to combat climate change and extreme weather conditions.

Mainstreaming TK into climate change adaptation policy framework has been proposed by experts for climate change adaptation since science simulation models alone are not able to combat climate vagaries in different ecological zones. Thus, requiring tailored measures to build the adaptive capacity of systems most especially in developing world which are beset with low adaptive capacity. Mainstreaming is to allow the integration of traditional knowledge and science knowledge systems to coproduce knowledge in framing adaptation and mitigation framework for specific agro-ecological zones employing multi–stakeholders. This is expected to result in social learning that could enhance social-ecological adaptive capacity with resultant resilience of systems to climate and extreme weather impacts and livelihood transformation.

Utilizing literature, the study highlights the perceived and observed changes and climate impacts of smallholder farmers, linking these observations to farmer management choices on coping and adaptation to climate and extreme weather events. Based on farmers' initiatives in combining both traditional and science technologies, the study explores the views and perception of other stakeholders on mainstreaming traditional knowledge into agricultural sector policy. Focusing on policymakers and influencers national and local on how the strategy for the integration of knowledge should be done to achieve social learning forming basis for collective or individual actions in adapting to the changing climate. Coupled with the anticipated barriers that may hinder the success of the process. This is visualized in Figure 1.2.

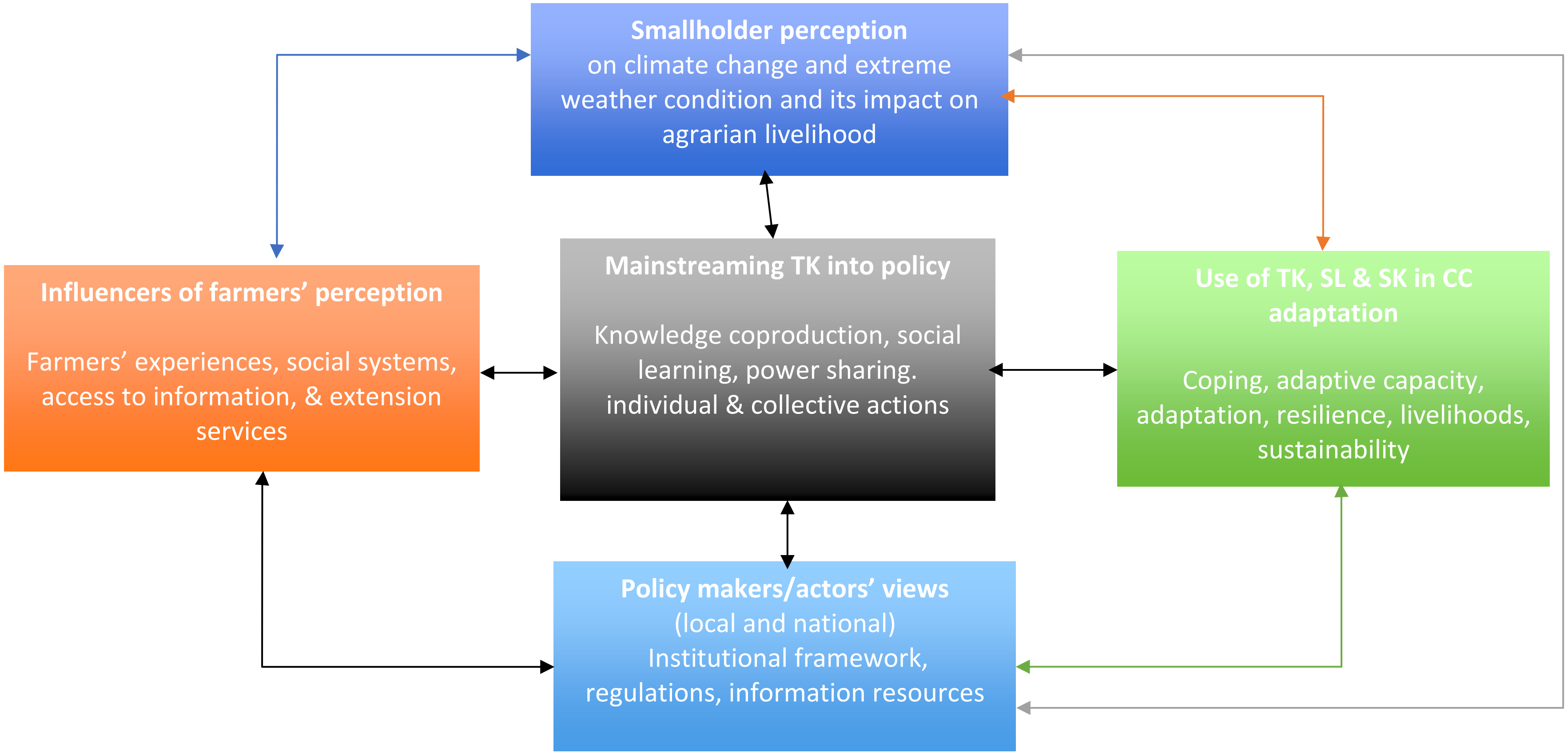


Figure 1.2: Conceptual framework

1.12 Ethics of the study

To identify and address appropriate ethical issues, approval was sought from Manchester Metropolitan University's Ethics Committee in accordance with the University's ethics policy before the commencement of primary data collection for this study. Two major themes could be drawn from the ethical guidelines for this study. Firstly, scientific research has the potential to create and cause harm to participants. Secondly, the research must aim to provide benefits to the participants. As the sole responsibility lies with the primary researcher to identify the potential risk associated with the study, providing strategies to prevent harmful practices and ensure potential benefits that will accrue to the individual and society (Orb et al., 2001). As such care was taken for human dignity, care for human welfare, consideration of both emotional and legal risk, and informed consent of respondents.

Thus, confidentiality of participants was ensured in terms of data processing and storage. Participants were informed about the purpose, methods, intended use, and storage of the information or data collected from them. Participants were made fully aware of their voluntary participation; as such, they could withdraw their participation anytime without obligations. Discussions on timelines were held with participants to ensure that the interview schedule did not pose any physical discomfort, distress, intrusion, or embarrassment to the participants. Another ethical consideration was using agreed upon terminologies in local dialect that participants will understand for the data collection. This helped to curb any discomfort that might have occurred from misunderstanding of the research topic by community participants.

Since the first part of the data collection was done during COVID-19 restriction period, as such, both participants and researchers were at risk to exposure to COVID-19 infection, considerations were made to observe social distancing and wearing face masks by researchers and offering of face masks to participants as required by COVID-19 protocols. Customarily handshakes in greeting were abandoned and the reasons behind it explained to participants.

The beneficial aspect of the research is the exchange of knowledge between researchers and participants. The researcher believed that ethically, farmer participants acquired an understanding and knowledge on why their farming methods were succeeding or failing amidst rapidly changing environment due to promptings from questions answered while awareness of policy maker and influencer participants of the need to incorporate TK into policies were enhanced. The researcher, however, acquired the necessary information needed for the study (Ethical Approval Number is 33884).

1.13 Overview of chapters

An overview of the thesis is as follows:

The first chapter introduces the thesis by presenting climate change and its impact on agricultural systems, emphasizing agriculture as mostly practiced in Africa. The chapter gives a brief introduction on smallholder farming and climate impact, traditional knowledge, and climate change adaptation, concepts on resilience, coproduction of knowledge and livelihood sustainability and mainstreaming of traditional knowledge into policy. Also, the chapter presents the statement of the research problem, goals, aims, questions the study is to answer, conceptual framework and ethics of the study and closes with the general overview of the chapters.

The second chapter presents the general methodology used for the study, which is a mixed method, with both quantitative and qualitative phases given equal priority. The study area consisted of two agro-ecological zones, with four districts selected from the two zones. Forty communities were engaged, ten from each district for the quantitative phase; eight focus group discussions with in-depth interviews were held for the qualitative phase in two communities in each district.

The third chapter assesses the perception and observation of climate change by farmers which have impact on their agro-ecological zone and livelihoods. This chapter examines how farmers perceive climate change, what factors cause climate variations, and their effects on farming activities. It also looks at how smallholder farmers access, interpret, and use weather information to counter climate impacts.

Chapter four assesses how smallholder farmers combine traditional and scientific technologies to adapt to climate change in their agro-ecological zone. The chapter uses two binary logistic models to determine factors that influence decision-making in adoption for land and crop management adaptation.

The fifth chapter examines how traditional knowledge could be mainstreamed into policy from the perspective of policymakers. Both national and local governments are aware of existing climate change policies, climate impacts in local communities, and how smallholder farmers adapt to climate change impacts using traditional technologies. The chapter discusses the possibilities of mainstreaming traditional technologies into policy, and the perceived barriers that may be encountered.

The last chapter provides general conclusions of the studies, assessing whether the initial aims and research questions were achieved and answered. Recommendations and areas for further studies are also elaborated.

Chapter 2

Methodology

The thesis adopted an approach where the study's objectives were converted into chapters under which each data set was presented and discussed chapter by chapter.

2.1 Research Design

2.1.1 Mixed method research

Mixed method research employs quantitative and qualitative methods in a single or multi-phased study (Tashakkori & Teddlie, 1998) at all or many research stages, including sampling strategies, data collection and analysis, synthesis of findings, integration, and reporting (Creswell, 1995). Data collected, analysed, and synthesised might be numerical or textual/visual/multimedia in nature. Tashakkori and Creswell (2007: p.4) define 'mixed method to be a single research or programme of inquiry that the investigator collects and analyses data, integrates the findings, and develops conclusions utilising both qualitative and quantitative techniques or methodologies.' However, to Johnson et al. (2007), the definitions proposed by the field's leaders have varying degrees of specificity, with the majority implying that what is mixed is quantitative and qualitative research, while some also include historical research in addition to the two paradigms already mentioned. Tashakkori and Creswell (2007) took into consideration how mixed methods can be found at different research stages. However, within the research paradigm mixing was referred to by other writers with some definitions specifying when or at what level of study that the mixing occurs. For instance, according to Tashakkori and Teddlie (2010) mixed methods research, mixes both qualitative and quantitative methods within a single study or in multiple phases of a study in the full process of research that include logical assumptions, research design, methods of data collection and analysis, and the interpretations of results.

2.1.2. Concept of integration in mixed method design

Recent proponents such as Plank Clark (2019:108) intimated that integration is the centre piece of mixed methods research where qualitative and quantitative parts of the study are mixed throughout the stages of the research processes. Creamer (2018:12) in defining fully integrated mixed method research stated there should be the intent to blend or integrate the qualitative and quantitative parts of study throughout each of stages or phase of the research process. This makes the distinctive quality that differentiates mixed method research from other studies. Integration could be viewed as the product of mixing, merging, connecting, and building qualitative and quantitative strands, such as mixing several types of data, and building a qualitative phase based on the results of an initial quantitative strand (Zhou & Wu, 2022). Fetters and Molina-Azorin (2017:293) introduced the concept of integration sequence as ‘‘an overarching concept that includes all dimensions (philosophers, ethicists, methodologists, applied researchers, and other academicians) consider a meaningful way for mixed methods approaches at the philosophical, methodological, and methods levels to inform an all-encompassing approach”.

Meanwhile, Teddlie and Tashakkori (2009), write that the study could utilize diverse designs, such as convergent, parallel, concurrent, sequential, and embedded designs. The designs used vary depending on the relative priority given to the qualitative and quantitative data. For instance, exploratory studies usually privilege qualitative data as little is known. However, explanatory studies which seek complementarity often prioritize quantitative data (Andrew & Halcomb, 2006). Also, mixed methods design varies at the integration point of the qualitative and quantitative data and such integration can happen at any point in the research process. For example, various philosophical approaches can be used to underpin the study, research questions can include both qualitative (why?) and quantitative (how often?) questions. Data collection can combine open-ended questions which collect narrative data and rating scales, or data analysis can cross tabulate themes and participant demographics (Andrew et al., 2008). According to Johnson (2017) and Schoonenboom and Johnson (2017), there is no single way to conduct mixed methods research, but mixed method studies share a common goal to produce robust and relevant conclusions. For complex research such as implementation studies, mixed methodology can explore a diversity of views and achieve results that increase contextual understanding and at the same time are generalizable to other settings. Additionally, mixed method research can draw from a variety of methodology and philosophical stances and combine to provide guide and build appropriate research process (Martel et al., 2022) since all research is underpinned by a set of assumptions about the nature of reality (ontology), theories about the nature of knowledge (epistemology), and the best way to go about increasing knowledge (methodology). Combined with the values of the researcher (axiology), these research paradigms influence the method and the design of the study (Zachariadis et al., 2013).

Limitations such as uncertainty in design due to the complexity of research needs require researchers to expand their research skills and experiences. Learning about new research methods and techniques to be qualified to conduct both parts of research (Yu, 2012; Molina-Azorin, 2016; Fetters & Molina-Azorin, 2017b).

The need for extensive data collection, for example, data collection in sequential design takes longer to complete (Halcomb & Andrew, 2009; Molina-Azorin, 2016). Additionally, the time-intensive nature of analysing both text and numerical data are some of the challenges associated with mixed method approaches.

This study used a mixed method approach to quantify and give detailed observations and strategies of smallholder farmers in describing climate impacts on their livelihoods. Johnson et al. (2007) described mixed method as an approach which involves using more than one approach or technique of design, data collecting, or data analysis within a single programme of study, with integration of the various approaches or methods taking place throughout the programme of study, rather than simply at the end. The method allows the research to explore new ideas that are not well comprehended, when findings from an outcome could well be explained by another source of data, when neither method (quantitative or qualitative) could be used to fully explain the concept under study alone, or when the quantitative results are such that qualitative data will help interpret and infer better (Creswell & Plano Clark, 2007). To explain and assign meaning to reasons behind farmers' choices in adopting techniques and strategies to adapt to climate change, the research required the use of mixed methods to allow for various designs. Also, the understanding of the complex experiences of farmers' perception of climate impact, its influence on management decisions, and the complexity of mainstreaming in policy-making, necessitate the intentional integration of quantitative and qualitative data in a mixed method research approach to maximise the strength and minimise the weaknesses of quantitative and qualitative methodologies (Creswell et al., 2011; Doorenbos, 2014) enabling an in-depth understanding of perspective of stakeholders making the mixed method approach appropriate for the study to achieve its aims and objectives.

Thus, the study is based on pragmatism since it is seen as the best philosophy suited for the combination of quantitative and qualitative methodologies in one study (Creswell, 2009; Maarouf, 2019). A sequential design involves qualitative and quantitative data being collected separately, with the findings from one data type collected providing a basis for the collection of a second set of data (Moline-Azorin, 2016). The study adopted Creamer's (2018) multi-phase sequential design in the collection of data. The quantitative data collected informed the type of data collected from the qualitative phase, clarifying certain findings, and meaning behind decisions of adoption by farmers. Also, integration was done throughout the research process – data collection, interpretation, analysis, and presentation of results (Creamer, 2018; Plank Clark, 2019; Zhou & Wu, 2022).

2.2 Data analysis

The data analysis was done using Predictive Analytical Software (formally SPSS 26) and NVivo 14 software to support coding of variables for both quantitative and qualitative data. Codes are short phrases or words that were assigned to parts of the data to capture the data's core message, significance, or theme. This step simplifies complex textual data by transforming it into a theoretical form and assisting in identifying elements related to the research questions using keywords identified in the data (Saldana, 2016; Naeem et al., 2023). Creswell (2015) asserted that coding is needed to break down dense textual data without which much time is required to go through to make sense of.

For the quantitative data, appropriate statistical analytical tools such as logistic regression, Chi Square test, non-parameter test statistics and cross tabulation were used. From frequency tables, themes generated from the unstructured questions were presented graphically for analyses. The interpretation of the findings was done through contextualization of concepts within existing research papers (Morse, 2016).

The qualitative data was first coded manually, and themes generated before transferring to NVivo version 14 software to support another coding and generation of themes for the data. The computer-aided analysis made it easier to detail the steps in the development of the interpretation and analysis. This makes it possible for the reader to re-trace the logical steps of the development and the basis for the conclusions of the study (MacLaren & Catterall, 2002). Also, effective documentation of the process enhanced transparency and rigour of the analysis process which facilitates replication of the study (Fielding & Lee, 1998). A deductive thematic analysis was applied for pattern identification and theme development guided by the theories and framework formed from the results of the quantitative phase (Braun & Clarke, 2006) for the interviews and focus group discussions. Since the interviews and focus group discussions were aimed to confirm the results from the quantitative phase and drawing out new ideas (Saldana, 2016). The voice data were transcribed, and researcher triangulation was used to verify the result of the script produced to fill in gaps. This was added to the written scripts made during the interactions, thus increasing the validity of the data collected (Burnard, 1991; Graneheim & Lundman, 2004). Community interviews and focus group discussions were conducted in the local dialects of the respondents using an interpreter, while the responses were written down in English during the sessions.

Secondary data analysis was through qualitative direct content analysis of the policy documents and district development plans manually by reading the documents with keywords or indicators such as traditional or indigenous knowledge or climate change (Hsieh & Shannon, 2005). The search covered strategies captured in the documents for adaptation of climate change from traditional knowledge alongside scientific methodologies. Weather data collected from Ghana Meteorological Services from the two agro-ecological zones were transferred into Microsoft Excel 2010 for graphical representation for interpretations.

2.3 Study zone

For this study, four districts were selected from the Sudan and Guinea savanna agro-ecological zones after a predetermined criterion (exposed to climate anomaly- drought) have been used. The inclusion criteria for the study districts that have been predisposed to climate and ecological change risks and abnormalities (temperature change; change in rainfall pattern; longer dry seasons). Kassena Nankana East Municipality, Kassena Nankana West, Bole and Sawla Tuna Kalba (STK) districts in the northern part of Ghana (Figures 2.1 & 2.2) were selected with additional characteristics to the criterion set. The districts were selected due to their similar characteristics such as highly vulnerable to climate and ecological changes due to their semi-arid physical characteristics and climate (Boafo et al., 2016; GSS, 2010); uni-modal rainfall pattern compared to the bi-modal pattern experienced in rest of Ghana (Aniah et al., 2019).

Additionally, the districts are mostly rural communities that depended on local systems to meet their livelihood needs (Boafo et al., 2014). Furthermore, the selection drew on preexisting connectivity of the districts with the view to check if traditional knowledge transferred orally **(**Wasti, 2023) has been adhered to over time. Another criterion checked for information from previous studies made on mainstreaming of traditional knowledge in climate change adaptation into development planning in the study districts (Mankodo et al., 2014).

Lastly**,** consultation and advice were sought from Agricultural Officers from MoFA in the northern regions based on the goals and objective of the studies (Antwi-Agyei et al., 2019).

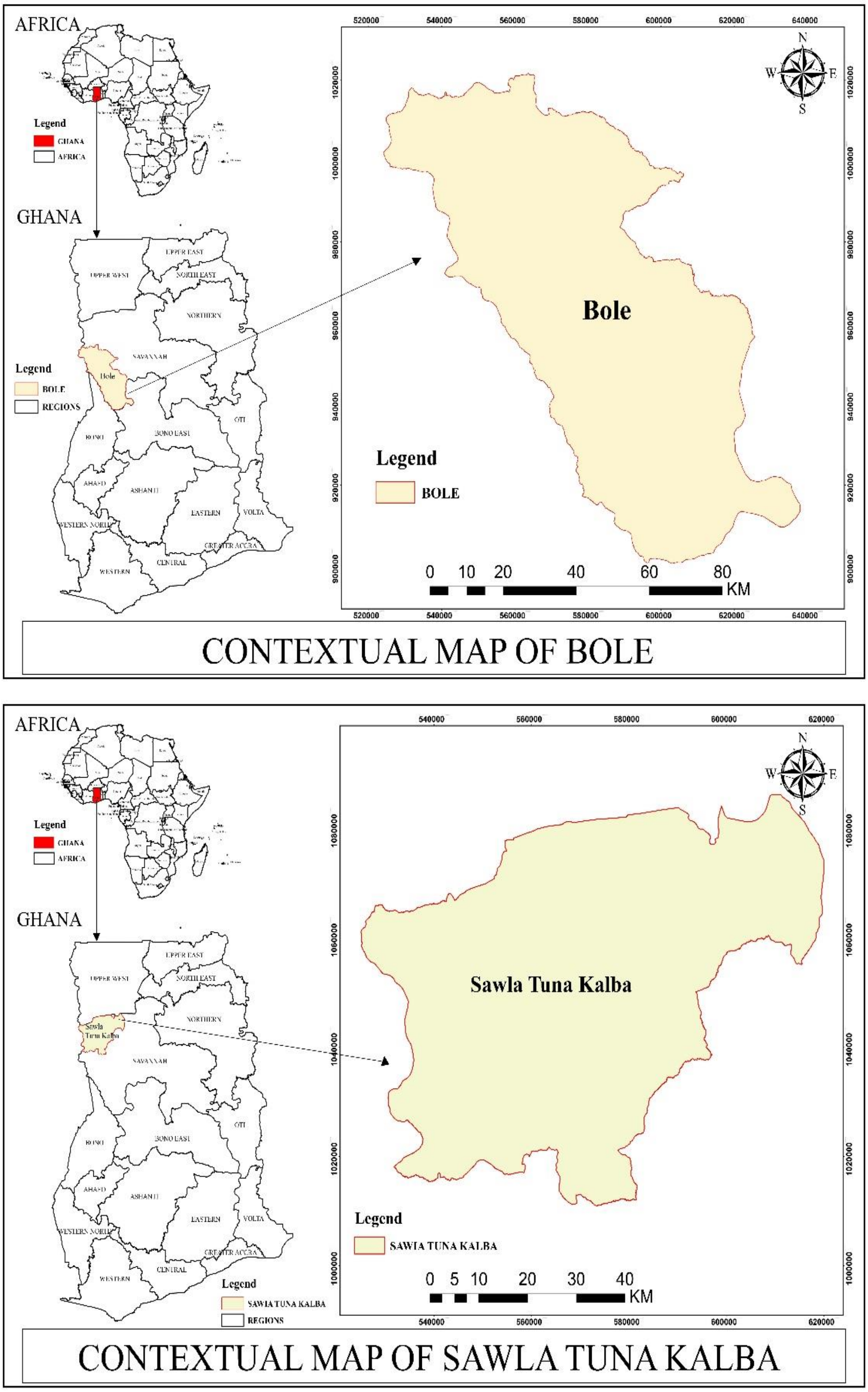
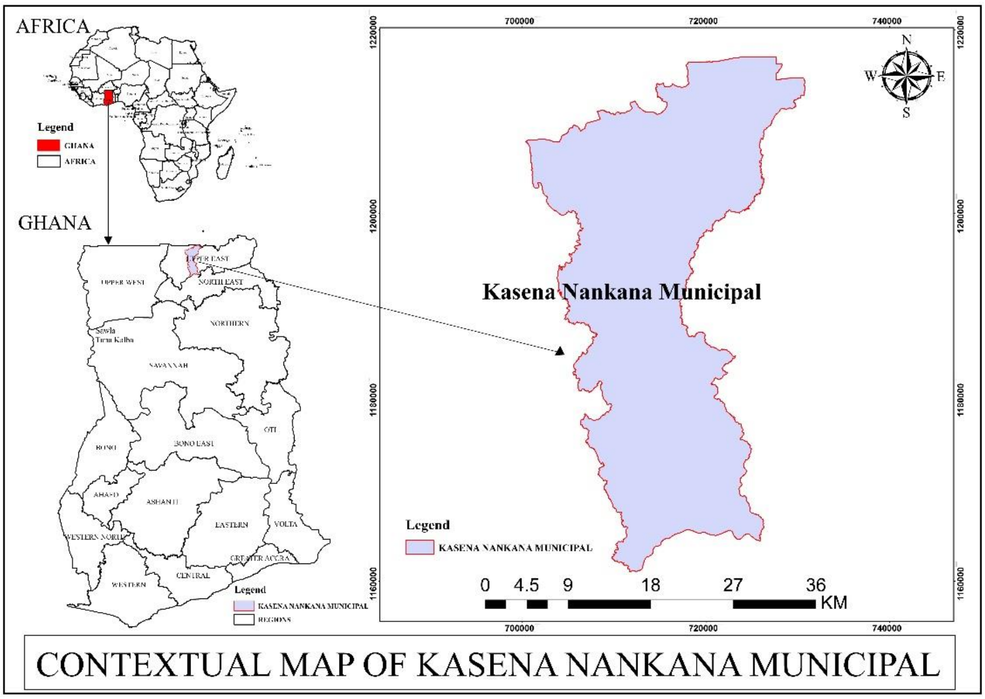


Figure 2.1: Map showing the study districts of Guinea savanna zone in relation to Ghana and Africa.



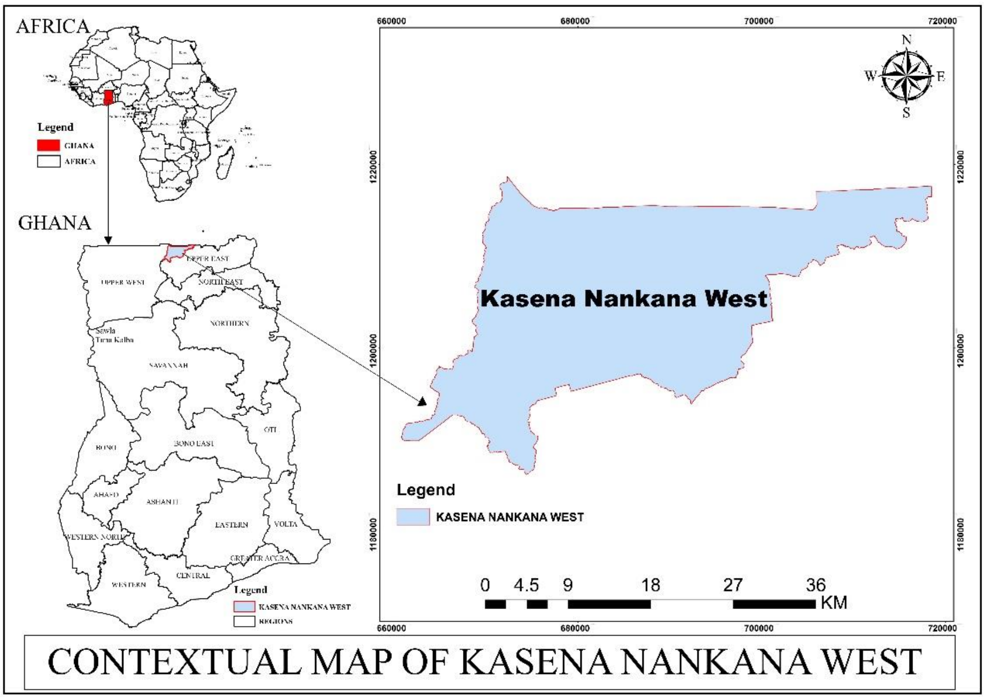


Figure 2.2: Map showing the study districts of Sudan savanna zone in relation to Ghana and Africa.

2.4 General characteristics of the study zones

The savanna agro-ecological zones of Ghana comprise the Upper East, Upper West, North-East, Savanna, and the Northern Regions in the northern part of Ghana. The zone is divided into two, namely the Guinea and Sudan Savanna zones, controlled by the rainfall amount and distribution (Figures 2.3). They are known to be highly vulnerable to climate and ecological changes due to their semi-arid physical characteristics and climate (Boafo et al., 2016). The zone is warmer than the rain forest of Ghana, with a uni-modal rainfall season between 600 and 1500 mm annually, accompanied by pronounced drought from late November to early March (Aniah et al., 2019). On average, the northern savanna ecological zones experience an annual rainfall of 1,100 mm compared to 1,300mm, 1,500mm and 2,200mm in the transitional, deciduous forest and rain forest belts, respectively (Dietz et al., 2004; Acheampong et al., 2014; MoFA, 2016). With projections of longer drought periods and shorter rainy seasons, as well as temperature change ranging from 0.6^{0}C in 2020 to 4.0^{0} C in 2080, there is an expected decrease in total rainfall from 1.1 % to 20.5 % from 2020 to 2080 across the agro-ecological zone (MESTI, 2015). Undoubtedly, this will deepen the erratic climatic patterns in the zone, making it the region most vulnerable to climate variations compared to other parts of Ghana. Also, the savanna zones have the highest poverty rate in the country, characterised by low income, malnutrition, ill-health, illiteracy, and economic insecurity), with levels ranging from 44.4 % to 50.4 % (Cooke et al., 2016; GLSS, 2018). Most of the population in the savanna regions live in rural communities, leading to a high reliance on local systems to meet their livelihood needs (Boafo et al., 2014). Most of the population (78 %) also depend on rain-fed agriculture, which is a blend of crop farming with livestock raising (GSS, 2014), with crop farming systems traditionally utilising hoes, organic fertilizer, and slash-and-burn, although gradual modification, such as use of tractor or animal-driven implements for clearing of land and application of inorganic fertilizers, is now being witnessed across the region (GSS, 2014). The predominant cropping system is the cereal-root crop "mixed cropping system," which is a combination of cereals, leguminous and root crop species (Callo-Concha et al., 2012). However, a slight difference occurs between the two zones. The cropping systems of the Guinea savanna zone have cereals, leguminous and root crop combination, while the Sudan savanna zone has cereals and leguminous crops in combination with dry season vegetable cropping.

Figure 2.4: Description of name of district, geographical location, weather pattern and main livelihood (agriculture)

District	Geographical Location	Weather Pattern	Agriculture
Kassena Nankana Municipal	Located 11°10' and 10°3' North and 10°10' West. Area is 767 km^{2}.	Rainfall pattern: Wet season: May to Oct. Average annual rainfall: 950 mm. Night temps: 26°C–28°C. Dry Season: late Nov to early March. Rainfall is entirely absent. Day temps are high, recording 42° C (Feb and March). Low temperatures 18°C.	96.1% households are involved in crop farming. 93.1% rural households are agricultural households.
Kassena Nankana West District	Located 10.97° North, 01.10° West. Area 1,004 km^{2}.	Rainfall pattern: Rainy season June–October. Annual rainfall between 950 mm. High temperatures: about 36°C to 38°C, March–April. Low temperatures: (about 28°C to 30°C) November–February (Harmattan period).	98.2% households involved in crop farming. In the rural localities, 93.4% engaged in agricultural production.
Bole District	Located: 8°10.5' and 09' North, 1.50E' and 2.45 ' West. Area is 6,169 km^{2}.	Rainfall pattern: Rainy season June–October. Annual rainfall between 1000 mm – 1500 mm. High temperatures: about 36°C to 38°C, March–April. Low temperatures: (about 28°C to 30°C) November–February (Harmattan period).	95% households are involved in crop farming. The rural localities have 71.1 % households engaged in agriculture production.
Sawla/Tuna/Kalba District	Located: 9 ° 17'0'' N, 2° 25' 0'' West. Area 4,227 km^{2}.	Rainfall pattern: Rainy season June–October. Annual rainfall between 1000 mm – 1500 mm. High temperatures: about 36°C to 38°C, March–April. Low temperatures: (about 28°C to 30°C) November–February (Harmattan period).	97.1% households are engaged in crop farming. 91.6 % of rural households engaged in agriculture production.

Source: GSS 2014: 2010 Population and Housing Census Analytic Report

2.4.1 Selection of communities

Twelve communities were selected from each district for the study (Table 2.1). In this study's context, the community refers to a group of local people who live and interact daily. The twelve communities were chosen because they share characteristics that could be researched in line with the goal of the study: (1) shared borders and similar livelihood activities that should have been or is being exposed to some sort of climate anomaly (particularly shorten rainfall and long dry seasons) (Antwi-Agyei et al., 2019; Anial et al., 2019); (2) substantial dependence on the local ecosystem to meet both primary and secondary livelihood needs (GSS,2014) and (3) easily accessible by transport [poor road networks are patterns in the northern region in general (GSS, 2010)] and the community must be prepared to partake in the study during its entire period (Anial, 2019). The selected communities were between 5 km and 10 km apart, making them easily accessible for the study. To have a wider spread of respondents, the communities for the qualitative phase were different from the ones for the quantitative phase. This is to give additional data and meaning to some findings, and to verify information from the first phase. The community selection was done in consultation with agricultural officials from the study zone, through a biased selection method, with inferences from the characteristics of the ecological zone according to reviewed literature (Antwi–Agyei et al., 2019).

Table 2.1: Districts and names of selected communities in northern Ghana, two agro-ecological zones for data collection activities for questionnaire administration, in-depth interview and focus group discussions.

District	Names of communities	
	Communities for administering of questionnaires	Communities for focus group discussions and interviews
Kassena Nankana Municipality	Akurugu, Daboo, Janania, Kongwani, Korania, Nangalikenia, Nayagnia, Nyangua, Upper Gaane and Vunania.	Kologu and Korania
Kassena Nankana West District	Baduno, Chiana Asunia, Chiana Sabonia, Kakungu, Katiu Asasong, Mirigu Tikongo, Mirigu Woligum, Navio Sanwo, Nyangania and Paga.	Mirigu Go and Nania
Bole District	Bale, Goli, Gbogdaa, Kiape, Kilampobile, Kpanyir, Lamporga, Mandari, Mankuma and Seripe.	Chache and Horiyiri
Sawla Tuna Kalba District	Blema, Digizie, Guruyiri, Jentilpe, Koonaar, Muiyiri, Muona, Nakpala, Nyange and Yorlyiri.	Bodi and Sanjeri

2.4 Sampling

The research used both probability and non-probability sampling methods. The probability methods were systematic and stratified sampling while the non-probability method was snowballing. In the probability sampling methods, the rule of probability applied ensuring every member of the selected population has equal chance of selection. The selected sample is a representative of the population, and the researcher can generalize the findings to the entire population (Naderifar et al., 2017). The farmer participants were systematically selected and to ensure representation, community members from age 25 years and older, as age is seen as a proxy for experience acquired in traditional practices in farming (Kibue et. al., 2015). Also, the study assumed that they have heard, observed, and experienced the use of traditional methods in farming for sufficient years to contribute meaningfully to the project. The key informant interviewees were purposefully selected using stratified sampling based on their position in the community or profession (district assembly members, district planning officers, district agricultural officers, development partner representatives and members of parliament) using quota sampling (Wasti et al., 2023).

The non-probability sampling used snowball sampling. Snowballing is a convenience sampling method applied when the targeted subject is difficult to reach. The existing study subject recommends future subjects among their networks (Parker et al., 2019). According to Polit-O'Hara and Beck (2006) snowballing referred to as 'chain method' is efficient and cost-effective to access people who would otherwise be exceedingly difficult to find. The first respondents referred as 'seeds' recommend others in their circles to the researcher as potential participants resulting in a chainlike reaction until data saturation (Wasserman et al., 2005; Parker et al., 2019). Some merits of the technique are often shortened time and diminished cost regarding gathering of participant group of sufficient size and diversity through recommendation (Naderifar et al., 2017). Wasserman et al. (2005) noted that participants can easily be identified based on set criteria and that the development of cultural competence and trust among potential participants enhances engagement. However, since the sampling depends on an initial small group of contacts, the research is at risk of becoming distorted at the onset of the research process (Parker et al., 2019). There can be ethical concerns if participants feel pressured to recruit others or if sensitive topics are involved. The dependence on the initial participants means the quality and diversity of the sample solely depended on them which may result in skewed sample if care is not taken in the recommendation process (Wasserman et al., 2005).

The study chose snowball sampling for the collection of data for members of parliament respondents after utilizing parliamentary procedures to engage select committee members without success making them fall under the difficult to reach category group using ordinary random sampling. The research used multiple entry-points (three seeds) as the initial respondents obtained from researcher's network to ensure sample is not skewed and help to reduce bias arising from using a single entry-point (Geddes et al., 2017). Each seed then recommended future participants to be contacted ensuring diversity and quality among the respondents. Also, the different initial seeds used served to incorporate anticipatory compensation for the potential imbalance in the recruited sample (Salganik, 2006). Data saturation was determined when no new information was added to the data when no new recruits were achieved (Parker et al., 2019).

2.4.1 Sample size

The quantitative phase of the study was based on a sample size calculation at a 95 % level of confidence (Daniel, 1999), with population projection figures from the four districts for ages 25 to 80+ years (GSS, 2020). A sample of 400 respondents were involved, based on the calculation, to ensure the validity and reliability of the findings' generalisation. A total of 100 respondents completed the questionnaire from each district from the two agro-ecological zones. Using the population (Table 2.2) from the four districts, a sample calculator for finite population correction was used to calculate size.

Table 2.2: Population figures for 2020 projected population by age in four districts in two agro-ecological zones in northern Ghana

Age Group	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80+	Total
Bole District	2,792	2,319	2,069	1,732	1,283	1,123	709	715	416	577	286	425	14,446
Sawla Tuna Kalba	2,615	2,218	2,078	2,090	1,794	1,846	1,154	1,504	806	882	497	811	18,295
Kassena Nankana Municipal	4,793	3,700	3,099	2,485	2,256	2,084	1,421	1,417	891	1,041	803	769	24,759
Kassena Nankana West	3,132	2,546	1,999	1,758	1,458	1,359	856	959	652	928	655	665	16,967
												Grand Total	**74,467**

Source: Ghana Statistical Services - Projected population by age, sex, and district, 2020

Using the Sample Size Calculator with the formula for finite population correction:

$n = z^2 * p * (1 - p) / e^2$

n (with finite population correction) = $[z^2 * p * (1 - p) / e^2] / [1 + (z^2 * p * (1 - p) / (e^2 * N))]$

Where:

n the sample size,

z is the z-score associated with a level of confidence,

p is the sample proportion, expressed as a decimal,

e is the margin of error, expressed as a decimal,

N is the population size.

Confidence level	95 %
p-value	0.5
error	0.05
alpha divided by 2	0.025
Z-Score 95 %	1.96
Sample size	382.17 ≈ 400

The sample size was approximated to 400 to give an equal number of participants of 100 in each district. The study therefore selected ten communities per district and ten participants each within a community for the quantitative phase.

The qualitative phase had 151 participants from eight focus group discussions (Table 2.3), eight in-depth community interviews, and 26 interviews with policymakers/influencers (district assembly members, district agricultural division officers, parliamentarians, NGO representatives and district planning officers) giving a total of 185 participants. Apart from the parliamentarians, all the others were drawn from the district level within the study area. The selection of community elders/opinion leaders was done in consultation with assembly members of the electoral area.

Table 2.3: Table showing district, community, and total participants for each focus group discussion

District/Municipality	Community	Number of participants
Guinea Savanna zone		
Bole	Chache – Men focus group	15
	Horiyiri – Female focus group	19
Sawla Tuna Kalba	Bodi – Men focus group	15
	Sanjeri – Female focus group	26
	Sub-total	75
Sudan Savanna zone		
Kassena Nankana Municipality	Kologu – Men focus group	12
	Korania – Female focus group	19
Kassena Nankana	Nania – Men focus group	13
	Mirigu Go – Female focus group	32
	Sub-total	76
	Grand-total	151

The elders and opinion leaders are distinguished, and influential (third parties) members of the community adjudge such by their years of service to the community or career (Elias et al., 2020) though, by definition (these category of community members can be classified as "gatekeepers" [(described as individuals, groups or organizations that act as intermediaries between researchers and participants and have the power to directly or indirectly facilitate or inhibit researchers ʾaccess (De Laine, 2000; Mandel, 2003; Wasti et al., 2023)]. The study used this category of community members as part of the respondents and their acceptance to participate gave extra credence to the study within the communities.

First, a list of categories of potential study participants as key informants (assembly members of electoral area of a study community; planning officers of the participating districts; development partners operating within the districts; agricultural officers of the participating districts and members of parliamentary select committees on environment science and technology and food agriculture and cocoa affairs) was made and quotas were set for these categories (Larkin et al., 2014; Wasti et al., 2023). However, the category set to include parliamentary select committee was abandoned when several attempts to get access to them through official channels as required by parliamentary procedures failed. The research then changed and used the snowball approach to reach this category of interviewees.

2.5 Data collection

The study used a quantitative and qualitative mixed method approach. Using Creamers' (2019) classification system of the mixed methods models, the study adopted a multi-phase design for the collection and analysis of the data, giving equal priority to both quantitative and qualitative components. Primary data collection for the quantitative phase was done using a mixture of both closed and open-ended questions in one questionnaire.

This ensured that respondents assigned reasons to certain choices in their adaptation method for their perceived or observed climate changes, enriching the development of the themes for the second qualitative phase. The qualitative phase used guides for both focus group discussions and in-depth interviews, developed from findings based on the quantitative phase and the literature review. To create a conducive environment (inclusive and equality) for the focus group discussions, physical seating arrangement was circular (Elias et al., 2020).

The secondary data were rainfall and temperature data over a ten-year period from two meteorological stations from the two agro-ecological zones of the study, extracts from the Ghana Food and Agriculture Sector Development Strategy II, Ghana Climate Change policy document, and districts' medium term development documents. Table 2.4 gives a summary of questions and data collection methods used.

Table 2.4: Description of summary of questions and data collection methods

Research question	Data collection method
To what extent are local farmers aware of climate variations in their operating zone over a ten-year period?	Questionnaire FGDs One-to-one interviews
What are the observed or perceived impacts of climate on smallholder farming and livelihoods?	Questionnaire FGDs One-to-one interviews
What strategies are employed by farmers to adapt to weather variations informed by traditional knowledge?	Questionnaire FGDs One-to-one interviews
	Questionnaire One-to-one interviews
Is there a plan in mainstreaming and institutionalization of traditional knowledge in policy at both district and national levels?	One-to-one interviews

2.5.1. Study Instruments

2.5.1.1 Questionnaire

Through the literature review based on the aims of the study, the questionnaire was developed to elicit information from the participants on their perceived or observed climate impacts in the local community and the strategies employed to combat them. The questionnaire (Appendix 8.1) was divided into sections, as follows:

a. Perceived and observed changes in climate.

b. Strategies adopted to combat the impacts of changing climatic conditions.

c. Information on the land and soil management practices and strategies, crop management and cropping systems used.

d. Access and use of weather information.

e. Accessing groups and extension agents in training and their impact on their farming activities.

f. Access to land use, in anticipation and in response to changing climatic conditions.

g. Biographical details.

2.5.1.2 Focus group discussions (FGD) and interview guides

The FGD guide was developed from the result from the quantitative phase, mostly to confirm and clarify some findings. The FGD guide had three sections (Appendix 8:3):

a. Observed climate change impacts.
b. Perceived changes in weather and climate impact.
c. Perceived threats or risks to their livelihoods and environment.

The interview guides were of two kinds, one for community engagement and one for policymaker interviews. The guide for policymakers addressed:

a. Awareness of climate impact on the community and techniques employed by smallholder farmers.

b. Awareness of climate change policy documents, content, and relevance to their responsibilities.

c. Views on whether smallholder farmer techniques based on traditional knowledge should be mainstreamed into policy, and perceived barriers (Appendix 8.2).

2.5.2 Quantitative phase data collection

The quantitative data was collected using an offline survey software from Lighthouse Studio 9.12.1. The questionnaire was developed with both closed and open-ended questions, giving respondents options and multiple-choice selection when required.

2.5.2.1 Maximum difference item scaling (MaxDiff)

The study utilised Maximum Difference item scaling (MaxDiff) technique in Sawtooth software for the simulation of respondents' strategic preferences in their farming methodologies in adapting to climate change variabilities. Although there are equally good scaling techniques, MaxDiff offered better scaling than standard rating or ranking exercises, and it was easy for respondents to answer the questionnaires compared to other methods. Also, MaxDiff had a fixed design that supported paper-and-pencil interviewing, an important feature that suited the remote research area, in the case of technology failure during the data collection. The MaxDiff scale allowed the respondents to evaluate 4 or 5 attributes to select the least and most preferred choices.

2.5.2.2 Training of research assistants

A day of training research assistants (Godfred Koio Kansake and Anthony Adonis Asagre, master's students from the C. K. Tedam University of Technology and Applied Sciences, Navrongo, Ghana) who are natives of the study communities. The research assistants were recommended by a lecturer from the mathematics department of their university after a discussion on the data collection activities and on the aims of the study. They were recommended because they had recent experience in national census data collection activity using local dialect after undergoing training within the research zone. In addition, the assistants' local knowledge of the terrain for the study engagement, a logistical consideration which cost effectiveness, proved favourable to employing a professional interpreter or assistants from the UK. The training for the assistants were accomplished via Microsoft Teams to address the collection of data and discuss the use of common local terms for the explanation of certain terminologies, to provide consistency in the data for easy transcription/interpretations. Furthermore, the assistants were taken through the ethics document on how participants are to be treated during interaction to ensure that they were comfortable to participate with an understanding of their voluntary status and their right to withdraw at any time. To cater for positionality during the interactions, research assistants were reminded to convey to participants of their importance in the survey exercise despite the researchers' presence in the community. The research assistants were also reminded to look out for females deferring (a culture practice by some communities) to male in public speaking as an aspect of gender positionality and ensure that interaction with females were not interrupted by their male counterparts. Where the situation cannot be helped, a new participant should be sorted for the engagement. A day before the actual data collection activity, the assistants were guided to use an app installed on Samsung Galaxy tablets. These assistants worked with the researcher throughout the field activities.

2.5.2.3 Pre-testing of questionnaire

Pre-testing of the questionnaire was done in July 2021 by two research assistants in two communities in the Sudan savanna zone. These assistants were selected as part of the study community with assistance from an agriculture extension officer. The resultant feedback was used to revise the questionnaire for the actual data collection. Revisions such as adding a few open-ended questions as follow-up to give more details e.g., Q41. The MaxDiff questions were added to the questionnaire. Also, the position of some questions was interchanged to create a logical flow that participants would understand. For example, Q17 was followed by Q19 after the pre-test result. Certain questions were re-phrased to make it clearer to participants (why it is or why is it not …. instead of if not…).

2.5.2.4 Participants engagement

The data collection took place between August 2021 and September 2021. The research assistants initiated the community entry. Obtaining consent for participation was done orally, after entering the community of prospective respondents and explaining the purpose of the study. The participants' intention of participation in the study was interpreted as giving their consent before the start of the administration of the questionnaires.

2.5.2.5 Sampling

The study employed a purposeful sampling technique by selecting respondents who are 25 years and above in age since local knowledge is passed on from generation to generation (Basdew et al., 2017). Based on the minimum legal employment age of 15 years for children (Children Act 1998), the study design assumed that by 25 years and above a farmer would have learnt and experienced practices in their farming for at least a decade. A systematic approach was used in the selection of households as constituting a group of people who own the same productive resources, live together and feed from the same pot, according to Yaro (2006). The researchers randomly selected a house from one end of the community. The first selected house became the baseline survey household. Then, every fourth house was selected as a survey household to engage participants until we had the required number of participants. This ensured a geographical distribution of participants in the community; the fourth selected house did not follow a straight line but went in a haphazard direction. Also, a skipped fourth house due to unavailability of prospective participants further enhanced geographical distributions. The questionnaire took between 30 and 35 minutes per respondent, ten in each community and hundred in a district, adding up to four hundred and three respondents.

2.5.3 Qualitative Phase

The second phase of the study, the qualitative phase, is intended to give meaning and reasoning to the previously collected quantitative data in terms of quality, the different manifestations, the context in which they appear, or the point of view from which they can be perceived (Busetto et al., 2020). The data collection took place between May 2022 and June 2022. Both focus group discussions (FGDs) and in-depth interviews (IDIs) were used for the qualitative components of the research design since according to Hammarberg et al. (2016), in-depth interviews help understand a condition, experience, or event from a personal perspective.

The FGDs were designed to fill gaps and give insight into “why,” “what” and “how” in the results obtained from the quantitative phase of the study. The FGDs were facilitated using a discussion guide to ensure that gaps and questions raised from the quantitative data collected were filled through consensus while taking on board additional information. The guide was divided into three, based on findings from the first phase: observed weather changes (change in temperature–day/night/dawn); water conservation methods (irrigation types, soil management type, materials used for composting); cropping systems used and their impact (change in crop type, dietary change); experience with agricultural extension officers, how farmers perceive climate change (threat or risk) and expectations from NGOs and government (district, regional and national levels) as a response to climate change effects on their livelihood. As community elders are seen as custodians of traditional and local knowledge, IDIs were conducted with them to explore further the traditional knowledge used in farming and the ways in which they have been adapting to changing conditions even before human-caused climate change era without any guide.

The FGDs and community interviews were done through an interpreter (one of the research assistants) and responses translated into English for recording. The assistant, more conversant with the local dialect spoken within the community, did the interpretation for the day while the other took notes, pictures, and voice recordings of the meetings with the researcher dubbing facilitation and note taking.

The IDI interviews with key informants/policymakers used an interview guide developed with information from reviewed literature on climate change and development planning in Ghana. The interviews were conducted in English by the researcher taking notes and recording at the same time.

Mopping up phase was done between 16–20th October 2023 with four community meetings (one in each district) as feedback session to further refine the results compiled during the analysis for validation (Aniah et al., 2019).

2.5.3.1 Sampling

The selection for the communities for the focus group discussions and interviews of elders was done in consultation with district agricultural officials and assembly members (Antwi-Agyei, 2019) to ensure that communities were different from the ones the quantitative date was collected from, giving a broader representation, and verified earlier findings by different sets of farmers. Two focus group discussions were held in each district: male and female group separately to create a more conducive atmosphere for women to speak freely during the discussion. This arrangement allowed sidestepping of a culture where women mostly stay at the background during discussions deferring to their male counterparts.

The sample of parliamentarians snowballed, as each interviewee gave the contact of a colleague (2.4). These colleagues were contacted to seek their participation until the number required was reached. Data collection used face-to-face interviews with local officials, while phone interviews were conducted with parliamentarians, since they preferred that over face-to-face interviews. Most of the parliamentarians requested the interview guide prior to the interview to ensure that the contents were not politically sensitive. The interview took between 25 and 30 minutes in English, with notes and voice recordings made after the interviewee had consented.

2.6 Data analysis

The data was exported to Microsoft Excel 2010 for cleaning to ensure consistency. The cleaned data was then imported to Predictive Analytical Software (formally SPSS) version 26 to support coding of variables for analysis for quantitative data. The notes and recordings from the FGDs and interviews were transcribed, coded, and analysed with computed aided support from NVivo 12 (refer to section 2.2).

Data from the structured questions from the quantitative data were analysed using logistic regression analysis and nonparametric tests (e.g., Mann–Whitney test, Kruskal–Willis's test and Chi-squared test). Also, using frequency tables and percentages of themes formed from the responses generated from the unstructured questions. Frequency and percentages for the themes generated were presented graphically using Microsoft Excel 2010. The mean monthly data for rainfall and temperature collected from two meteorological stations in the research districts were graphically plotted using Microsoft Excel 2010 (Figure 2.3). Additionally, a MaxDiff preference scale was used to rate farmers 'preference for soil fertility improvement techniques and weather information delivery.

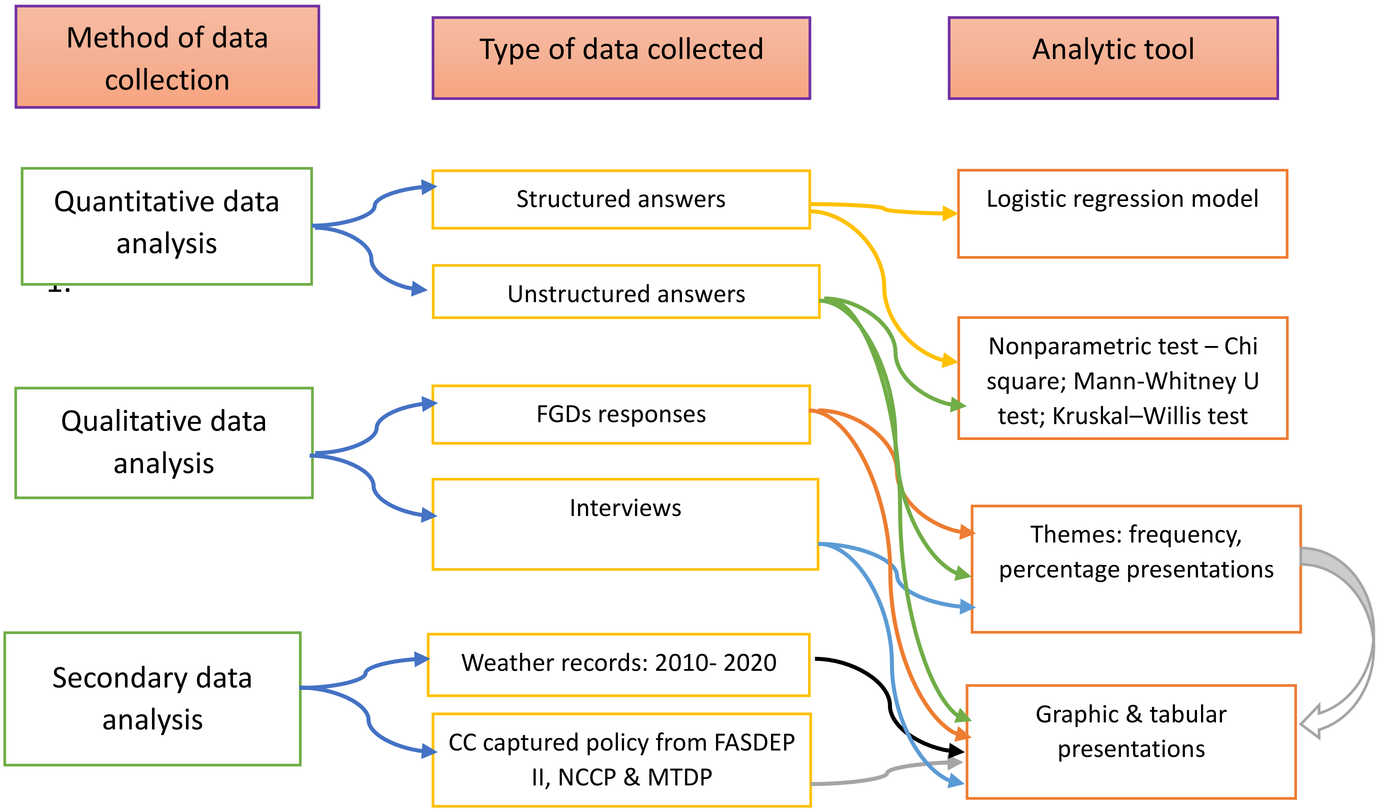


Figure 2.3: Descriptive summary of type of data and analytical tool for data analysis of the study

For the qualitative data, major themes were identified through intensive content analysis from generated codes and indexing (Krippendorff, 2018). Structuring the themes allowed for putting responses into categories that enabled the identification of those that diverged from the common themes. The information from the focus group discussions, community key informant interviews and feedback sessions were used to triangulate any contradictions observed in the data from the quantitative phase. This ensured that threats to qualitative data validity and reliability are eliminated (Patton, 2014; Aniah et al., 2019). Also, some information was quantified and plotted using Microsoft Excel 2010 to give a better understanding of the findings. Some additional quotes were sourced from FGDs to enrich the data by selecting statements that aligned with themes formed from the generated codes (Yamba et al., 2019).

2.7 Research limitation

A limitation of the study was its reliance on stakeholder information (interviews) in line with data gained in the context of social studies, where individuals are sources of information. However, the perceptions of the participants are based on and influenced by firsthand experiences and opinions, among other factors. Additionally, people remember what is most important to them, and this may be influenced by their occupation and experiences. Furthermore, people's knowledge and responses change over time. The memory failure of how long farmers could remember is addressed by filling in gaps using responses from the multiple methods from devise participants using researcher's triangulation. Time was a constraint due to the domiciliary nature of the researcher; fieldwork scheduled within a certain period posed a challenge when the respondents seemed not available. Aspect of the study could best be done using ethnographic study instead of focus group discussions, this would have given the researcher more details of the nuances of farmers day-to-day farming decisions but due to financial constraints, the research had to use alternative methodologies.

2.8 Positionality Statement

Reflexivity according to Robson (2002:22), is defined as 'an awareness of the ways in which the researcher as an individual with a particular social identity and background has an impact on the research process.' According to Lazard and McAvoy, (2017), reflexivity is a form of critical thinking that involves addressing the issues of identity and positionality by making the researcher's assumptions explicit and finding strategies to question these. As a Ghanaian woman scholar and researcher with an agricultural science background, in reflection, I may have influenced the research area chosen for the study, seeing myself as one with years of experience in community interactions for knowledge production (Mao et al., 2016; Jacobson & Mustafa, 2019; Holmes, 2020). Using the pragmatic research paradigm (Creswell & Tashakkori, 2007; Feilzer, 2010; Biddle & Schafft, 2015) which is grounded in the belief that both singular and multiple realities can be explored through empirical investigation, this approach emphasizes practical solutions to real-world problems (Feilzer, 2010). The effect of climate change impacts and adaptation on farming communities in the global south is one such situation that needs to be investigated. The paradigm advances scientific knowledge using research design and adaptable methodological approaches (Biddle & Schafft, 2015) giving researchers the flexibility of design choices required in mixed method methodology.

The qualitative phase of the research utilized focus group discussions and interviews of participants that required face-to-face interactions or phone calls for the data collection. Reflecting on my own activities and those of my assistants during fieldwork, we were perceived as both insiders and outsiders, highlighting the complex nature of our positionality in the research context. I was positioned as an insider by virtue of my nationality as a Ghanaian. However, as a PhD student from a foreign country and a different tribe, it made me an outsider. Meanwhile, the assistants' outsider status was from their position as master's student from the university and insiders because they were native speakers (Milner, 2007; Dill & Kohlman, 2012; Mao et al., 2016). In view of these positions, we played both roles as when needed on the field. For instance, during the focus group discussions and key informants' interviews, participants were made to understand that they were the source of information for the research required due to their experience acquired over the years from farming and interacting with their environment. Emphasis was laid on the cyclical seating arrangement used during the focus group discussions that signified equal standing in the interactions. Also, the inherent outsider position I held meant that some participants expected me to convey issues they were facing due to the topic under discussions to 'authorities' on their behalf or provide solutions to them in the future. An example was when a female focus group participant asked after the engagement; 'what is going to be done about climate change, and it impacts on our livelihood.' However, as an insider and an educated woman, some of the female participants viewed me as a potential voice that could courier their plight to the authorities that be, for solutions or gather resources elsewhere to help them. To counter such expectations, we made the objectives as an academic activity clear at the onset and as part of the concluding statement, categorically stating that participants would gain information/knowledge from the interactions. As intimated by Mullings (1999), the binary function in the insider/outsider debates of the researcher was less than real because the roles had to be switched depending on the time and space since no individual can remain an insider consistently or outsiders completely throughout the process.

The interviewer and interviewee relationship that assumed exchange of information to be beneficial was an interesting one since at a point the information assumed a status of a currency, a means of exchange (Robertson, 2022). This also could be equated to processing of power which according to Bordo (1993:191) within the Foucauldian approach "the fact that power is not held by anyone does not mean it is equally held by all. It is "held" by no one, people and groups are positioned differently within it, and no one may control the rules of the game. But not all players on the field are equal." This information seeking by participants took place after the scheduled interview where I then became the potential source of information. For instance, a local planning officer who was offering his master's degree used his study as an excuse to delay being part of the interview until he had enquired from me about how to secure PhD funding in the UK. This led to his interview occurring via WhatsApp after the field activities were done and I had returned to the UK. Also, a local assembly member told me to help him secure a scholarship for a masters' programme in the UK after the interview session. These indicated the power shifts in the power conceptions, since the two individuals used their information sharing by exerting power differently.

According to Cotterill and Letherby (1994), "familiarity," can reduce initial problems of access and this was used for entry of communities for the fieldwork. Based on the insider researchers' knowledge of local power players and how they often try to influence methodology for community engagement. Of the two foremost power players (traditional and official), the official route (assembly members and agricultural officers) was contacted as gatekeepers[1]. This proved to be the best option since negotiations were mostly one-off cases, one would say the presence of the research assistants who knew most of them personally or through referral for initial contact. However, given that these gatekeepers also held influential positions within the community, it is important to reflect on how their involvement may have impacted community members' participation raising questions about whether individuals felt compelled to take part. While their presence lent legitimacy and credibility to the study, it may also have unintentionally influenced the voluntariness of participation.

In conclusion, researchers and researched have roles to play for the research process to be complete, a dynamic that is influenced by how the researcher is perceived on the field. This dynamic is constantly influx requiring the researcher to be attentive to react to it when needed. Although one's experience and knowledge of research area can be valuable in methodology for data collection, the continuous nature of changes that occur in primary research data collection require that researchers be flexible in conceiving alternative plans that would satisfy the conditions of the research aims and objectives for success.

[1] Individuals, group or organizations that act as intermediaries in the research process with the power to directly or indirectly to facilitate or inhibit researchers' access to prospective participants (De Laine, 2000; Mandel, 2003).

Chapter 3

Smallholder farmers perceived or observed changing climate and its impacts

Objectives 1: To determine the farmer-level information on the degree of observed and perceived climate changes and extreme climate variations.

Objectives 2: To identify manifested climate impacts on farming practices in two selected agro-ecological zones.

Research question 1: To what extent are local farmers aware of climate variations in their agricultural zone?

Abstract

The perception of one's environment has always been considered a determining factor in how one interacts with the immediate environment. Smallholder farmers' perceptions or observations have an impact on their farming activities, through which they interact with their environment for their livelihood and sustenance. Farmers' perceptions have been shown to be influenced and modelled by their personalities, experiences, evidence obtained, and the traditional and environmental settings in which they live and interact, which are mostly subjective. Thus, the smallholder farmers' perception of change in their environment influences their farming choices in ensuring farm yields while protecting the environment.

This chapter examined if smallholder farmers in northern Ghana have perceived or observed changes in their environment and how their perception has influenced their on-farm decision-making and the impact of the changes on their livelihood.

The study showed that smallholder farmers have observed or perceived decreases in soil moisture, increases in temperature, more irregular rainfall, high intensity of the rainfall, shorter rainy seasons, and longer drought periods in both agro-ecological zones. They mentioned that negative human behaviour, deforestation, natural weather phenomena, and belief systems are the causes of climate change. Also, studies showed that climate impacts communities' farming, economic, and environmental activities, leading to deepening food insecurity. To adapt to these changes, farmers are changing their cropping systems, shifting

planting dates, and using weather information either through traditional prediction or scientific weather data delivered (in local languages) conventionally through radio or major television news casts. Farmers, however, mostly access weather information on daily rainfall patterns and distribution, and maximum and minimum temperatures, to aid in their farm decisions. The farmers also preferred direct interactions with public agricultural extension agents for extension delivery. The study concluded that for smallholder farmers to build resilience, the agriculture service delivery, including climate information, must be tailored for effective use by farmers for farm decisions and management for the sustainability of their livelihoods and the rural economy. Also, since agricultural agents are at the center of service delivery, they must be well equipped to deliver the required services and advice.

3.1 Introduction

Climate change perception is the way a person sees, comprehends, explains, and assesses climate change by observing its impacts while interacting with the environment and community (Munhall, 2008). Smallholder farmers ' perceptions of climate change and its impact is influenced by components of social and cultural systems that influence observations of, and responses to climate change, which affect decision-making and governance in the short- and long-term (IPCC, 2018). Farmers' perceptions of climate change have been based on its impact on their immediate environments. Such impacts include increasing temperatures, declining amounts of rainfall, irregular rainfall patterns (amount and distribution), reduction in crop yields, and increasing prevalence of disease and pest infestations. Farmers' perceptions of climate change leads to the assessment of its related risks, resulting in management of the risk by adopting strategies to adapt the farming system to climate impacts for sustainability. However, the effectiveness of adaptation planning is determined by how farmers perceive and respond to the climate risks involved (IPCC, 2018). In the food-climate relationship, success or failure of adaptation depends on farmers ' knowledge and perceptions of the risk involved and the access to available resources required for adaptation.

3.1.1 Perception

The term perception is defined according to the discipline using it (Soubry et al., 2020). For instance, Bennett (2016) indicated that perception is loosely defined depending on the situation in conservation literature. Baul (2013), for example, defined perception as the acquisition of information from the immediate environment, altering it into physiological awareness. Instead, in social science, the term refers to how reality is perceived and experienced to recognize and shape responses to form behaviour and actions (Fetterman, 2008).

In the environmental context, perception is a cognitive, emotional, and cultural process of understanding and responding to the natural world - an act of observing and learning to protect and care for the environment (Savietto, 2014). Within the conceptual framework of climate adaptation, perception is explicitly referred to as an individual's link with climate-based risks (Soubry et al., 2020).

The process of understanding climate change perception is complex and includes a range of psychological constructs, such as expertise, convictions, styles, and queries about if and how the climate is changing (Whitmarsh & Capstick, 2018). However, perceptions are always subjective, since it is always a person's or a group's distinct way of observing a phenomenon and interpreting it by adding their individual experiences and memories to inform their actions (McDonald, 2012).

In general, an individual's view of climate change is based on complex social, moral, psychological, institutional, and cultural processes that influence how people perceive climate change, potential solutions, and individual attitudes and behaviour towards it (Leiserowitz, 2005).

3.1.1.2 What influences perceptions?

Knowledge is vital to perception because it gives meaning to the perceived impacts of the environmental phenomena of an individual; included are immense experiences and understandings that influence the perception of people in their environment (IPCC, 2014b). For instance, van der Linden (2015) indicated that perceptions are influenced and shaped, among other things, by one's characteristics, experiences, evidence received, and the cultural and environmental setting in which they live. Several relational factors, past experiences, and individual and collective attributes influence perceptions (Moon & Blackman, 2014; Levine et al., 2015).

However, Marques et al. (2020) stated that perception is based on more than what is seen. It is also affected by necessities and wishes to improve upon the experience and knowledge accumulated or overcome certain situations. For example, the result of the many influences on perception in climate change adaptation at the local level is that opposing groups and entities can observe the same situation in hugely diverse ways.

Thus, according to Satterfield et al. (2009), people's perceptions can change over time, and decisions are often subject to persuasion. Nevertheless, perceptions are said to be context and location specific, as influencing factors are different, such as culture, education, gender, age, endowed resources, and institutional factors (Posthumus et al., 2010). For example, the media influence climate change perception based on how the issue is framed and communicated (Metag et al. 2017; Brevini and Lewis 2018). Brevini and Lewis (2018) continued to show that a person's perception of climate change is affected by how the media and other sources of information framed the problem. Even in some cases, behavioural change influences decisions for or against climate actions (Taddicken, 2013; Metag et al., 2017).

But according to Whitmarsh and Capstick (2018), there are many factors that can influence public perceptions of climate change, such as weather and weather events, economic factors, socio-political circumstances, and press coverage, while individual-level factors, such as a person's outlook and philosophy, are crucial. Also, perceptions are directly influenced by the share of principles and ideals within a community and the physical experience of weather changes (Ruiz et al., 2020).

3.1.1.3 Empirical evidence of farmers' perception of climate change and adaptation

Each farmer has their own experiences of changing climatic conditions and their impact on production that influence decision-making. Farmers' perceptions, according to Ayeri et al. (2012), are observations of meteorological and climatic events made throughout time that may then be used as adaptation methods.

Other studies, such as Chérif et al. (2016), claimed that farmers' views are formed from applied knowledge that emerges from actual settings. Yet others continue to believe that they are inexorably related to local knowledge (Gamble et al., 2010). But Ngute et al. (2021) reported variations in the quantity and allocation of rainfall, fog, and heat, with the meteorological data on rainfall and temperature in accordance with local perceptions of changing weather situations. Although farmers' perceptions were contrary to meteorological data, Owusu et al. (2021) found that farmers from three agro-ecological zones in Ghana had perceived a longer drought period with shortened farming seasons due to climate change and adapted by cropping early maturing maize cultivars. Similarly, Ayal and Leal Filho (2017) revealed that farmers' views about temperature changes were like meteorological data analysis, though they were contrary to rainfall trends. Meanwhile, in Nigeria, Onubuogu and Esiobu (2014) found that farmers' perceptions of climate variations were like evidence of trend analysis in terms of declining number of raining days and relative humidity, in addition to rising temperature and sunshine duration. Additionally, local perceptions of changing temperatures and rainfall in India were like an analysis of 108 years of temperature and rainfall data, as well as different agro-met data such as sun intensity and windspeed (Tripathi & Singh, 2013). Furthermore, Dickinson et al. (2017) showed that farmers’ views of inconsistent rainfall patterns and dry conditions as weather changes in their locality were supported by meteorological data sets. Though farmers mentioned that increased windy conditions persist, their observations varied spatially within the districts of northern Ghana. They, however, attributed the altered climatic conditions to a decrease in forest cover. Likewise, Balasha et al. (2023) showed that farmers’ views on changing climate aligned with the local historic weather log, which indicated an increasing temperature shift and decreasing rainfall over a ten-year period. These occurrences were predominant between 2013 and 2019. Teye et al. (2015) noted that farmers in the northern savanna zone of Ghana’s awareness of increasing temperature and decreasing rainfall is hugely consistent, with evidence of variations logged by weather stations. The findings are linked with gender and access to information. Climate impacts reported from three agro-ecological zones in Nepal included decreasing farm production, food insecurity and water stress, assigning changes in weather phenomena, commercial activities, and religious factors.

However, a review of farmers' experiences and perceptions by Karki et al. (2020) revealed that farmers around the world have been observing changing weather conditions in terms of increasing temperature and inconsistent and declining rainfall, coupled with a reduction in agriculture production. Similarly, Zizinga et al. (2017) showed that local people in south-western Uganda’s perceptions of climate change shifted with the seasons and prevalence of rainfall for the last 30 years. Farmers, who could afford to do so, adopted soil conservation practices to adapt to the changes. Also, smallholder farmers, as reported by Gedefaw et al. (2018) from Qwara district in Ethiopia, perceived a change in climate, including elevated temperature, declining rainfall, and severe winds. This was coupled with a decline in production due to decreasing rainfall within the growing period, which then became excessive during harvesting resulting in produce quickly rotting in the fields. Ali et al. (2020) linked smallholder farmers' awareness of climate impacts with adapting irrigation and early planting policies in rural Pakistan. But most smallholder farmers observed an increased annual mean temperature, which manifested in the number of hot days recorded, in addition to a decline in annual mean rainfall over a 10-year period and a decline in rainfall days (Kgosikoma et al., 2017).

3.1.2 Climate change information

Climate information delivery, though a recent concept, has gained prominence due to climate change. It is said to be an effective tool in decision-making for farmers in adapting to climate variation. Belkin and Pat (1989) defined information as the result of processing, altering, and organising data in a way that adds value to the understanding of the recipient. Rezvanfar et al. (2007), however, pointed out that information is needed because of its significant impact on the living activities of humans. But in this age of information explosion, according to Mudukuti and Miller (2002), the spread of information and the application of this information in the process of agricultural production play a vital role in the development of farming communities and economies. Moreover, Hamooya and Ngoma (2019) argued that for agriculture to be successful, it requires information, and in this respect, information plays broad and multi-faceted roles. Access to agricultural information is considered a critical component of a cutting-edge agricultural system, and a prerequisite for greater output (Rehman et al., 2013; Yusuf et al., 2013; Yaseen, 2016). To this end, the UN (2004) and FAO (2014) showed that access to relevant information had a significant impact on agricultural enterprises, as it enables farmers to respond to different types of risks and market enticements and to compete more efficiently (Hamooya & Ngoma, 2019).

Conversely, Saadi et al. (2008) and Singh et al. (2011) argued that farmers need the latest information on new agricultural practices, cultivation techniques, crops, seeds, pesticides, water management, marketing, government agriculture policies, the export potential of their crops, and timely provision of all necessary inputs to compete in the modern global market. The provision of agricultural information is therefore a critical component of a sophisticated agricultural system, as well as a fundamental and necessary booster of agricultural development, which helps improve the livelihood of rural farmers (Yaseen et al., 2016). Information is also essential for boosting agricultural output and strengthening marketing and distribution plans (Oladele, 2006).

Some empirical studies also claim that knowledge and information are the most significant components for speeding agricultural growth through proper production planning, purchase of modern inputs, higher agricultural output, and enhanced marketing and distribution (Poole & Kenny, 2003; Bertolini, 2004; Lio & Liu, 2006). Therefore, a farmer must possess the crucial ability to recognise and comprehend what might be useful information. However, according to Mtega et al. (2016), current global climate change conditions have increased the necessity of providing agricultural information on adaptation and mitigation methods. Such information is crucial in industries such as agriculture, where stakeholders heavily depend on the environment to adapt to the impacts of climate variations (Mwingira et al., 2015).

Additionally, adequate climate change knowledge effectively prepares farmers to adapt to adverse circumstances (Nkeme & Ndaeyo, 2011). Hence, appropriate climate change information transmission is therefore an essential component for efficient adaptation (Popoola et al., 2020). In this vein, Vaughan et al. (2018) opined that climate services, which are billed as the development and distribution of pertinent customised information for decision-making at all levels of society, have attracted a lot of interest recently. However, weather and climate services require the timely creation, translation, and transmission of practical weather and short-term climate information suitable for use and generated in forms that may be incorporated into societal decision-making processes (Vaughan et al., 2016).

With effective communication, public outreach, and education, support can be boosted for policy and collective action for behaviour change, which is the key factor in the context of anthropogenic climate change (Moser & Dilling, 2007). To be effective, agricultural information should be provided to rural communities depending on their requirements (Adejo et al., 2016). Hence, forecast data is only useful if farmers can access and use it, and if it suits their requirements and context (Thornton et al., 2011; World Bank, 2012). This suggests that simply having access to predictive information is insufficient. For example, if an early warning system properly forecasts a drought, but does not provide vulnerable individuals with the knowledge they need to survive, the information's use is limited (Mudombi & Muchie, 2010).

Climate change information transmission to rural farming populations is crucial, and a lack of it may cause hesitation in pursuing agriculture, since one of the key problems impeding agricultural output is a lack of information on supply chains and marketing opportunities (Yaseen et al., 2016). According to Nkeme and Ndaeyo (2013), farmers' failure to take up adaptation measures is due to a lack of awareness, understanding and distribution of information on climate change. But access to accurate knowledge about climate change implications raises awareness and may boost farmers' adaptive skills (Shongwe et al., 2014).

Similarly, other studies attested that farmers' decision-making is hampered by restricted access to information and services, which makes them more vulnerable to the hazards of climate change (Drafor, 2016; Angello, 2017; Ameru et al., 2018; Mapiye et al., 2019). Thus, there is the need to provide timely and accessible weather information to farmers to improve farmers' decision-making during planning of farming activities (Baffour-Ata et al., 2022). Furthermore, Mbanda-Obura et al. (2017) and Anadozie et al. (2021) indicated that there is evidence supporting farmers' ability to manage their daily difficulties and make the most of the available resources, which is weakened by a lack of suitable information and encourages conflicting perspectives and poor decisions. Piabuo et al. (2020) inferred that rural farmers are not receiving timely information, resulting in the delayed growth of the rural small-scale farmers' community in sustainable agricultural development activities.

Apart from information supply, Zougmoré et al. (2016) hypothesised that the ability to adapt to changing climate conditions depends on available capital, infrastructure, technologies, social institutions, and networks. But the lack of communication devices owned by farmers impeded their ability to access weather information. Also, there were records of doubts of some farmers on information on weather and climate forecasts and the lack of pictorial representation of information understandable by farmers, according to Baffour-Ata et al. (2022), that hinders the use of climate information by smallholder farmers.

3.1.2.1 Type of climate information used by smallholder farmers.

Baffour-Ata et al. (2022) reported that smallholder farmers in northern Ghana mostly receive information on rainfall, temperature, and windstorms, which is delivered as daily or weekly predictions with little to no seasonal predictions. Likewise, Agyekum et al. (2022) asserted that although weather predictions of rainfall and temperature assist farmers to combat climate variations by prior planning, farmers can access daily or weekly forecast information in place of seasonal information, which is much needed for longer-term planning. But Bachhav (2012) showed that farmers required daily information for various agricultural tasks, while Baffour-Ata et al. (2022) discovered that few farmers use seasonal predictions. However, according to Baffour-Ata et al. (2022), access to weather information varies even within the same region.

Most farmers were more interested in receiving forecasts for rainfall, such as the expected amount and distribution of rainfall, and temperature, such as the intensity of the dry season (Antwi-Agyei et al., 2021c). Similarly, Lebel (2013) in Asia, Mudombi and Nhamo (2014) from South Africa, and Shackleton et al. (2015) in Europe reported that rainfall and temperature information is vital for smallholder farmers in managing climate impact and risks to their livelihood. Furthermore, most study findings reveal that crop farmers mostly received information on rainfall and temperature. The information included the beginning and ending of rainfall within a season, how the rains dispersed, the extent of rains, the intensity of the dry season, the length of dry spells, and the strength of the wind during the rainy season (Rasmussen et al., 2015; Amegnaglo et al., 2017; Diouf et al., 2019; Radeny et al., 2019; Antwi-Agyei et al., 2021c).

Yet, there is often a mismatch between available information and what is needed to support on-the-ground decision-making (Antwi-Agyei et al., 2021c). In support, Nyadzi et al. (2019) and Gbangou et al. (2019) concluded that in designing climate information dissemination, considerations should be taken to determine delivery to understand when it will be most useful to the farmer in terms of their decision-making.

3.1.2.2 Sources of climate information

A source of information is a means for storing knowledge and/or information, or in other terms, is defined as everything that contains and/or stores data (Bitso, 2012). As a result, information sources are seen as vital for the efficient distribution of information. Sani et al. (2014) showed that information sources are classified based on their mode of representation: textual, graphic, and audio-visual.

Discussions on the availability, efficacy, efficiency, and overall influence of information on farmer productivity have been held over the years (Olajide, 2011). According to Moser and Ekstrom (2010), access to climate change information is critical for coping and adaptation responses. Mtega et al. (2016) asserted that access to information is determined by the infrastructure necessary for its distribution, which is often unevenly dispersed within and between nations, making some agricultural communities more information-rich than others. Lamontagne-Godwin et al. (2018) indicated that information must reach farmers in a medium that is usable, clear, or pictorial for farmers with lower levels of formal education.

Also, information access by farmers must take place in an easy and convenient location or on radio (Lamontagne-Godwin et al., 2018). The most basic sources of information for rural farmers were neighbouring farmers, family members, and traditional mass media such as radio and television (Mbanda-Obura et al., 2017; Maguire- Rajpaul et al., 2020; Popoola et al., 2020; Baffour-Ata et al., 2022; Awuku-Manteaw, 2022). However, other sources mentioned included input suppliers, sale intermediaries, NGOs, newspapers (Mtega et al., 2016; Popoola et al., 2020; Awuku- Manteaw, 2022), extension agents (Yaseen et al., 2016; Baffour-Ata et al., 2022), town criers and film shows (Maguire-Rajpaul et al., 2020), district authorities, village gatherings, mediators, and farmer cooperatives (Lwogo et al., 2014; Qiao et al., 2018). In addition, ICT–based sources such as internet and mobile phones (Mittal & Mehar, 2012; Motiang & Webb, 2015). However, Rezvanfar et al. (2007) and Nawab et al. (2020) showed that most female farmers depended on friends, husbands, neighbours, and other native sources, like local leaders and educated people for their information needs. Similarly, Lwogo et al. (2014) and Nawab et al. (2020) indicated sources such as government offices, personal experience, village or community leaders and farmer groups. Hassen et al. (2007), however, explained that farmers had easier access to friends and family members than other information sources, making them the most preferred source of information after personal experiences. According to Patel et al. (2012), although farmers prefer information from scientists, they responded better to information from their peers. Hence, small-scale farmers passed on their knowledge to their neighbours, friends, relatives, and children mostly through casual conversation, experience sharing, and visits to other farms (Habtemariam et al., 2015).

Farmers in developing countries primarily rely on face-to-face communication for agricultural knowledge, though they also access diverse sources, including cooperative associations, which support market access, capacity-building, and bargaining power. The variety of their information needs is reflected in the wide range of sources they consult (Msoffe & Ngulube, 2016; Qiao et al., 2018; Nawab et al., 2020).

3.1.3 Extension Services

According to Danso-Abbeam et al. (2018), extension programs are vital for disseminating agricultural technologies, enhancing farmers' technical and managerial skills, and promoting rural learning. These services aim to increase productivity, income, and food security. Thus, public extension is seen as a critical link between farmers and researchers, helping to facilitate technology adoption (SNRD, 2016; Raidimi & Kabiti, 2019; Mapiye et al., 2019; Angello, 2015).

However, several challenges hinder their effectiveness. Rehman et al. (2013) and Mapiye et al. (2021) emphasized the need for reforms to improve delivery, focusing on recruitment, training, and logistics. Despite its importance, extension services often suffer from poor design, limited resources, and an overly top-down approach (Angello, 2017; FAO, 2017; Anang et al., 2020). These issues result in services not being tailored to farmers' needs, leading to low usage (Swanson & Rajalahti, 2010; Siddiqui & Mirani, 2012).

Moreover, farmers' reluctance to engage with extension services may stem from inefficiencies, a shortage of agents, and logistical constraints (Agbarevo, 2013; Akpotosu, 2017). Maguire-Rajpaul et al. (2020) argued that Ghana's current agricultural information systems are insufficient, and that informal farmer-to-farmer knowledge exchange remains an underutilized asset that could enhance the design and effectiveness of extension programs.

3.1.4 Summary

According to Soubry et al. (2020), the definition of perception varies across disciplinary contexts. However, within the scope of climate change, it is commonly viewed as a cognitive process shaped by psychological constructs and personal interpretations regarding whether, and in what ways, the climate is changing (Whitmarsh & Capstick, 2018).

Perceptions are inherently subjective, influenced by individual and communal experiences, philosophies, shared values, and direct encounters with climate variability (Ruiz et al., 2020), all of which inform how environmental phenomena are observed and understood (McDonald, 2012). As such, perceptions are highly context-specific and evolve over time in response to shifting environmental, social, and institutional dynamics.

Furthermore, media narratives and external framings of climate issues significantly influence public understanding, alongside economic pressures, institutional arrangements, and sociopolitical conditions (Brevini & Lewis, 2018; Whitmarsh & Capstick, 2018). These factors collectively shape how smallholder farmers perceive climate change, their responses to it, and the types of solutions they consider feasible.

Research has shown that farmers' perceptions play a critical role in shaping agricultural decisions, particularly in the adoption of climate-resilient technologies and practices (Deressa et al., 2009; Ayeri et al., 2012; Ayal & Leal Filho, 2017; Antwi-Agyei et al., 2021). Empirical studies indicate that many farmers' perceptions align with scientific observations, such as prolonged droughts (Deressa et al., 2011; Owusu et al., 2021), erratic rainfall (MESTI, 2015; Ndamani & Watanabe, 2016; Osei, 2017), and increasing temperatures (Adjei-Nsiah & Kermah, 2012; Antwi et al., 2018; Yamba et al., 2019). However, there are also documented cases where these perceptions diverge from empirical climate data (Ayal & Leal Filho, 2017; Owusu et al., 2021).

Given the importance of perception in guiding adaptation strategies, inaccurate or misinformed views may heighten the vulnerability of smallholder farming systems, particularly those reliant on rain-fed agriculture and lacking access to adaptive technologies (Pereira, 2017; Leal Filho et al., 2015).

This misalignment can pose serious risks to food security and rural livelihoods. Therefore, a nuanced understanding of the socio-economic factors that influence farmers' climate perceptions is essential for enhancing resilience and supporting sustainable agricultural development. This chapter explores smallholder farmers' awareness of climate change, their perceived impacts on farming activities, and the broader implications for resilience and sustainability in rural agricultural systems.

3.2 Materials and methods

3.2.1 General characteristics of the study zone

The study was conducted in two agro-ecological zones of northern Ghana that are characterised as among the most vulnerable to climate change variations when compared to other zones in the country (refer section 2.3).

3.2.2 Methods

The study used mixed method models for the collection of data (refer to section 2.5).

3.2.3 Data analysis

The data was collected using an offline survey software from Lighthouse Studio 9.12.1, exported to Microsoft Excel 2010 for cleaning. (refer to section 2.6).

3.3 Results

3.3.1 Characteristics of farmers

The greatest number (114) of farmers fell within the above 55 age range, with the least (71) between 25 and 35 years, since age is seen as a proxy for experience acquired in traditional farming practices (Kibue et al., 2015). One hundred and thirty-five farmers were recorded in both zones as heads of households, compared to 66 as members of households (Table 3.1). Most farmers (178) had no formal education, but there was a disparity in the education levels of farmers in the two zones, with a clearly greater proportion of farmers in the Sudan savanna having some form of schooling (Table 3.1). This can potentially influence decisions on adaptation methods between the zones, based on the assumption that the level of education of farmers exposes them to information that affects their decisions on the farm. The comparison of results showed that 42 farmers had no education in the Sudan savanna zones, compared to 136 farmers from the Guinea savanna zone.

Table 3.1: Characteristics of farmers: age category, position in households and level of education in two agro-ecological zones in northern Ghana

	Age categories of farmers			
Agro – ecological zone	**25 – 35**	**36 – 45**	**46 – 55**	**Above 55**
Guinea Savanna	30	55	53	53
Sudan Savanna	41	49	50	61
Percentage proportion of farmer participants.	17.7	25.9	28.1	28.4

	Position in household	
Agro – ecological zone	***Head of household***	***Member of household***
Guinea Savanna	135	66
Sudan Savanna	135	66
Percentage proportion of farmer participants.	67.2	32.8

	Level of education achieved						
Agro – ecological zone	**None**	**Primary School**	**Junior/High/Middle School**	**Secondary School**	**Vocational School**	**Tertiary**	**Night School**
Guinea Savanna	136	28	22	7	1	2	5
Sudan Savanna	42	41	42	32	4	20	20
Percentage proportion of farmer participants.	44.3	17.2	15.9	9.7	1.2	5.5	6.2

3.3.2 Observed/ Perceived climate change variations.

The majority (96.5 %) of the surveyed farmers observed or perceived climate change variations in terms of decreases in temperature and soil moisture, increases in temperature, irregular rainfall, higher rainfall intensity, shorter rainy seasons, and longer drought periods (Figure 3.1). However, between the two ecological zones, farmers gave varied responses for longer drought periods, shorter rainy seasons, increased rainfall intensity, irregular rainfall pattern, increase in temperature, low intensity in rainfall decreased soil moisture, and decreased temperature, which were statistically significant, using Non–parametric tests (Table 3.2).

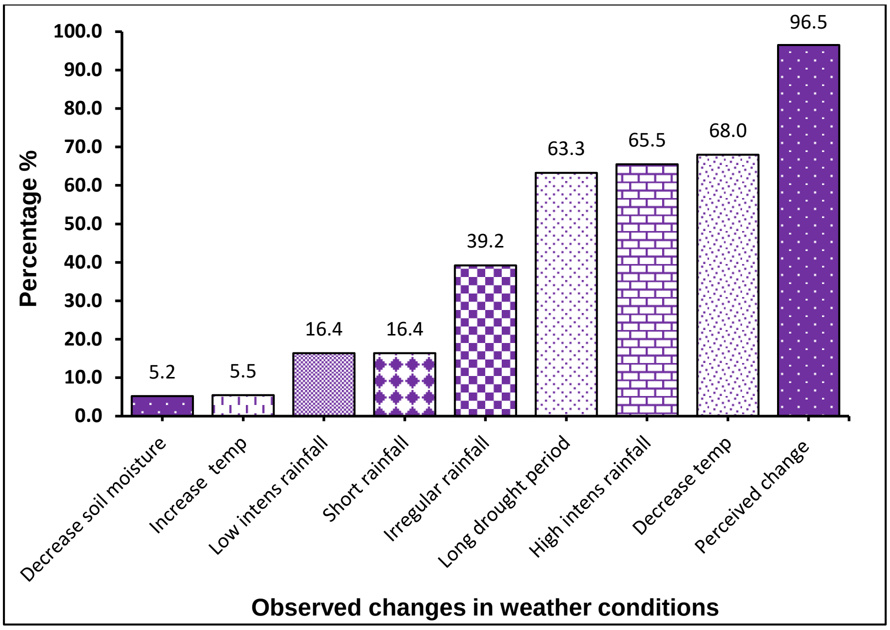


Figure 3.1: Description of farmers observed/perceived changes in weather conditions in two agro-ecological zones in northern Ghana.

Table 3.2: Test statistics for grouping variables for two agro-ecological zone in northern Ghana using Mann-Whitney U tests showing differences in responses on observations of climate changes (Long drought period, short rainfall period, high intensity rainfall, irregular rainfall pattern, increase in temperature, low intensity rainfall, decrease in soil moisture and decrease in temperature).

	Long drought period	Short rainfall period	High intensity rainfall	Irregular rainfall pattern	Increase in temperature.	Low intensity rainfall	Decrease in soil moisture	Decrease temperature
Mann-Whitney U	16783.5	15075.0	14974.5	18391.5	20100.0	19798.5	18291.0	11557.5
p-value (2-tailed)	<0.001	<0.001	<0.001	0.066	0.823	0.591	<0.001	<0.001

Grouping Variable: Agroecological zone

This was consistent with Yaro's (2010) conclusion that with fluctuating characteristics, the direct and indirect impacts of climate change are specific to different socio-geographical zones and livelihood groups and sectors, supported by Uddin et al. (2014) in a farm level study in Bangladesh. Despite these disparities, the farmers' observation of irregular rainfall patterns, shorter rainy seasons, and longer drought periods is consistent with the literature (MESTI, 2015) and rainfall recorded from 2010 to 2020 at two meteorological stations located in Bole in the Guinea savanna zone and Navrongo in the Sudan savanna zone (Figures 3.2 and 3.3). The farmers' varied response may be due to the different impacts of climate change. As exhibited by the contrasting rainfall patterns, the Sudan savanna zone (Figure 3.3) showed much more variation with longer dry periods, compared to the seemingly consistent rainfall patterns with shorter dry periods in the Guinea savanna zone (Figure 3.4).

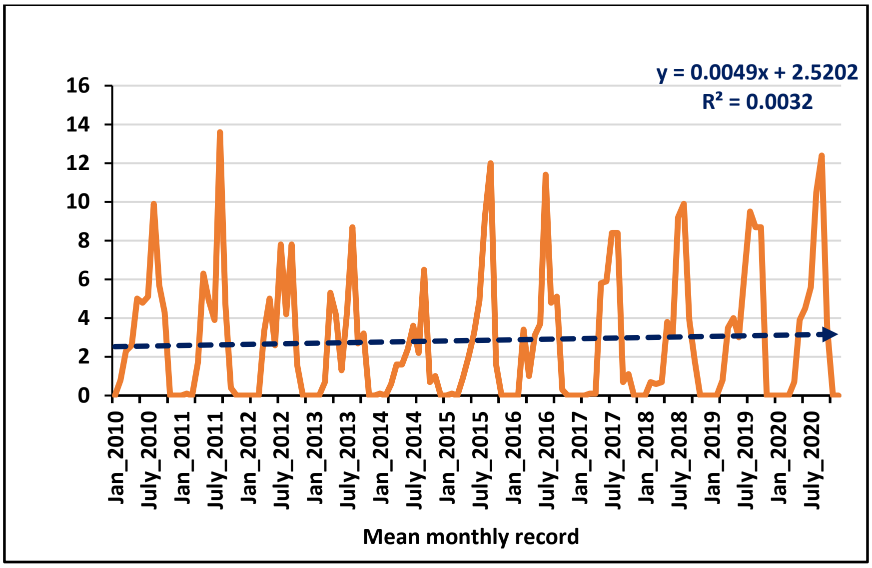


Figure 3.2: Mean monthly rainfall recordings in Sudan savanna zone of northern Ghana from Navrongo meteorological station (2010-2020)

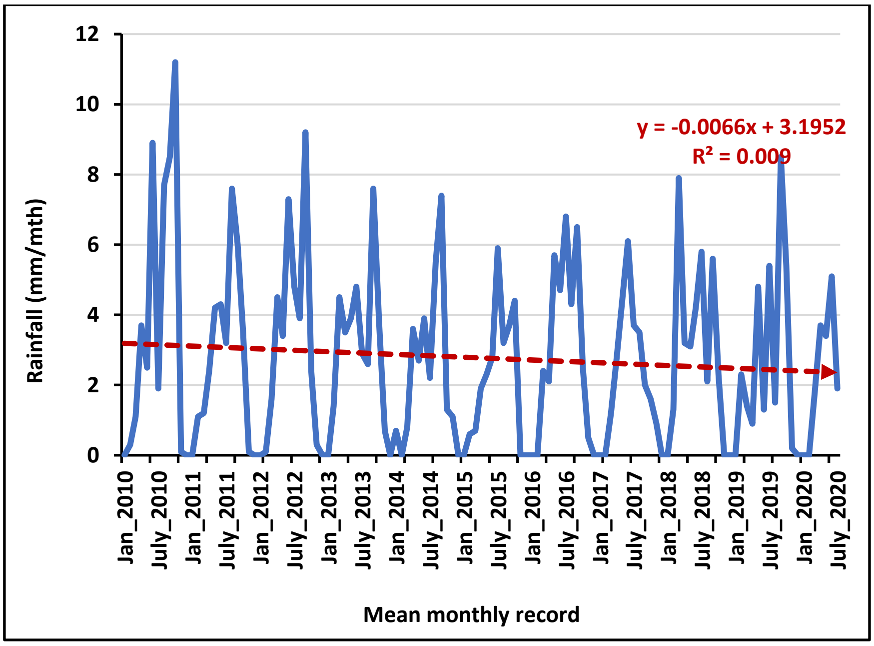


Figure 3.3: Mean monthly rainfall recordings in Guinea savanna zone of northern Ghana from Bole meteorological station (2010-2020)

Furthermore, results from the farmer perceptions for irregular rainfall patterns, increase in temperature, and decreased intensity of rainfall were not statistically different between the zones using the non–parametric test (Mann–Whitney test: U= 18392, p = 0.07; U= 20100, p = 0.82; U = 19799, p = 0.59 respectively, N1 = 201, N2 = 201, two–tailed).

Interestingly, the results showed that only 5.5 % farmers observed increasing temperatures, when compared to 68 % who observed temperature reductions in both zones, contrary to existing literature that indicates increasing temperature trends of 1 ^{0}c for the rest of the century (James & Washington, 2013; Engelbrecht et al., 2015). In addition, the plotted temperature trend (Figures 3.4 and 3.5) of mean monthly temperature records (2010 –2020) of two meteorological stations depicts a slight increase in both the minimum and maximum temperatures. This could be likened to an observed report by farmers from Yaro (2010) that the weather was “confused” and difficult to predict accurately due to the range of divergence over the years of inconsistent weather conditions.

Source: Monthly mean temperature trend from data - Bole meteorological sub-stations

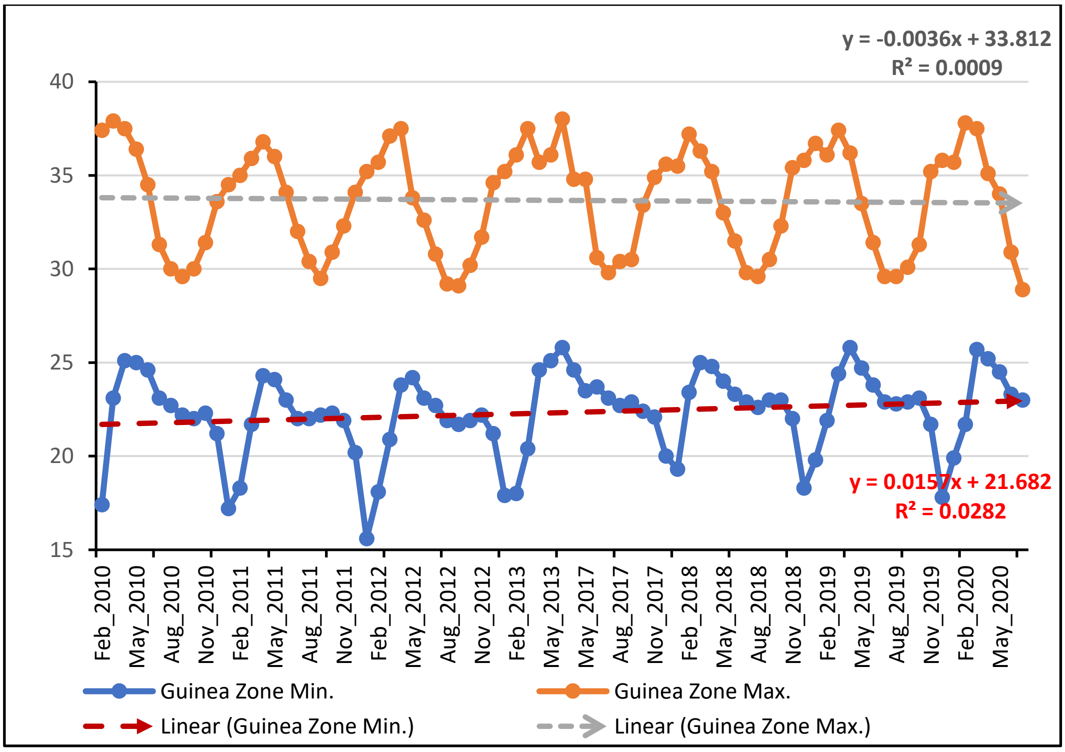


Figure 3.4: Mean monthly temperature (minimum and maximum): Bole meteorological station in northern Ghana (2010-2020)

Source: Monthly mean temperature trend from data - Navrongo meteorological sub-station

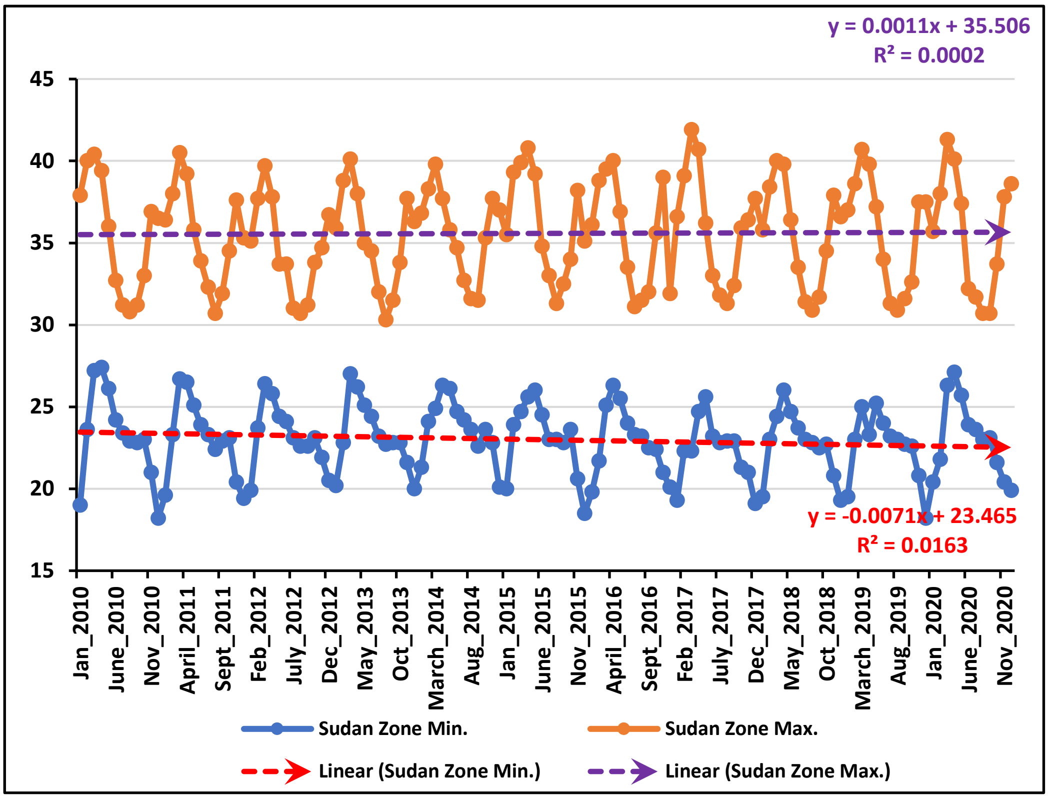


Figure 3.5: Mean monthly temperature (minimum and maximum): Navrongo meteorological station in northern Ghana (2010-2020)

However, all discussants from the focus group and key informants from the communities observed a rise in temperature, contrary to the majority (68 %) of farmers from the quantitative phase, in accordance with literature and plots from the local meteorological data of a ten-year period. As expressed by a female discussant from Guinea savanna FGD: "*It's too hot in the day that you cannot work on the farm, and too hot in the night that you are not able to sleep."*

They specified a rise in both day and night temperatures, attributing the cause mostly to loss of tree cover, which has led to exposure to the direct rays of the sun. This was expressed better from a male discussant from Guinea savanna FGD: *"Where are the trees to provide shade and absolve and reflect the sun's rays?"*

Furthermore, all the discussants confirmed changes observed in weather patterns, supporting the findings from the quantitative phase. They indicated changes such as irregular rainfall patterns that have been happening for the past ten years. They also noted the uncertain start of the rainy season, making it difficult to determine when it will start each year unlike in the past, when farmers could estimate the onset of the season based on previous patterns. This gives an indication of climate impact observed in the communities, the Guinea savanna zone discussants mentioned that the rainy season now starts in May and ends in October compared to a decade ago, where the season lasted from March to November as stated by male discussant from Guinea savanna FGD: *"We used to have rains around Easter, but these days Easter is as dry as hell."*

Also, the discussions revealed the shortened rainfall season from six months to three months with a long drought period in between as the cause of reduction in crop yields. The high intensity of the rainfall and winds mostly lead to the washing away of topsoil resulting in loss of nutrients from the topsoil with gradual decrease in soil fertility. The intense rainfall leads to increased surface run-off and reduced infiltration into the soil, resulting in insufficient soil moisture available for crops during the season. The issues are compounded by the shortened rainfall duration. This was emphasised by an elder from the Sudan savanna zone: "*It is not the duration, but the intensity of the rains that is causing destruction to our farms and properties."*

The discussions revealed early morning dew as a specific weather phenomenon that no longer exists due to climate change, resulting in poor yields in late millet production as commented by a male discussant from the Sudan savanna FGD: *"The morning dew helped the late millet mature after the rain had stopped before harvesting, since it no longer exists, our late millet yields poorly."* This is consistent with findings by Ogalleh et al. (2012) of farmers in Kenya's Laikipia district identifying the non-occurrence of maguna ng'ombe (local reference of first rain that occurred in February; short rains for three days to support sprouting of grass for livestock) since 2000 as a remarkable change in their climate.

3.3.3 Factors contributing to changes in weather patterns.

In terms of the causes of changes in weather, 26.3 % of the farmers indicated negative human behaviour that included excessive use of agrochemicals, indiscriminate felling of trees without replanting, seasonal bushfires from charcoal production and uncontrolled fires set to clear farmlands (Figure 3.6). Also, activities of Fulani (migrants) cattle herders that result in overgrazing. However, claims regarding activities of Fulani herders may be partially influenced by inter-ethnic tensions stemming from a long-standing conflict between the herders and the locals. This led Adomako (2019) and Kugbega and Aboagye (2021) to recommend educating farmers to discourage antagonistic views of pastoralists alongside an independent, fair, and trustworthy system of dispute resolution.

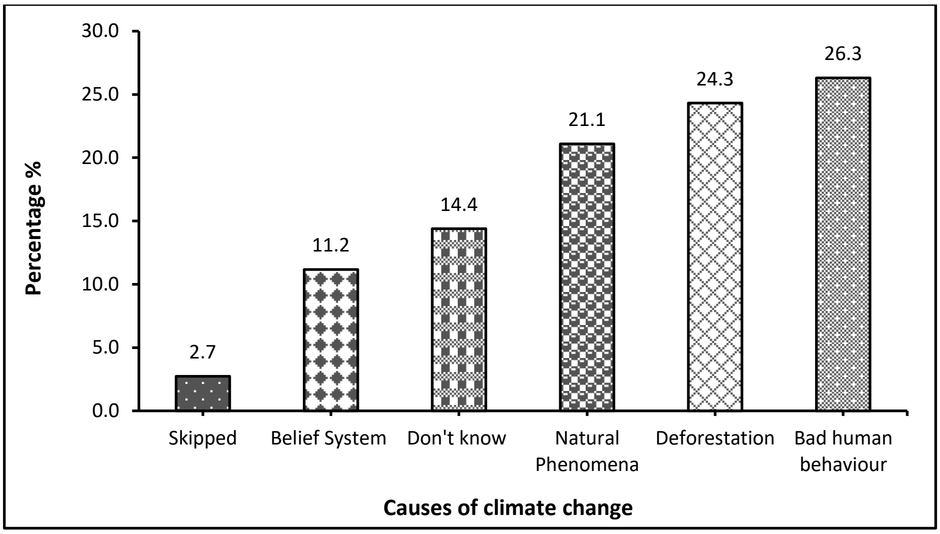


Figure 3.6: Description of factors causing climate changes as observed by farmers in two agro-ecological zones in northern Ghana.

A further 24.3 % also indicated the cutting down of trees without planting in addition to the expanding desert, while 21.1 % mentioned natural phenomena such as intensive rainfall and longer droughts, which they believe humans have no control over. Though the majority (71.7 %) of farmers attributed the changes in weather to human activities over the years, none mentioned the use of fossil fuel as a factor. Consistent with Yamba et al. (2019)'s findings in southern rural Ghana, which also did not mention the use of fossil fuel as a contributor to climate change. However, 11.2 % farmers stated that change in weather is due to disobedience and violation of cultural norms and the work of God. This is consistent with Iaccarino (2003)'s assertion that people's cultures are rooted in traditional beliefs used by indigenous communities in understanding and interpreting of the biophysical environment.

3.3.4 Impact of climate change on livelihood of small-holder farmers

Farmers indicated that the changing weather conditions have had severe impacts on their livelihood since they depend mostly on subsistence farming. The majority (80.1 %) of farmers mentioned poverty and hunger as the worst impact felt by the changing weather. They attributed these impacts to poor yields that result in investment losses, which restricts their ability to feed and support their family needs (Figure 3.7).

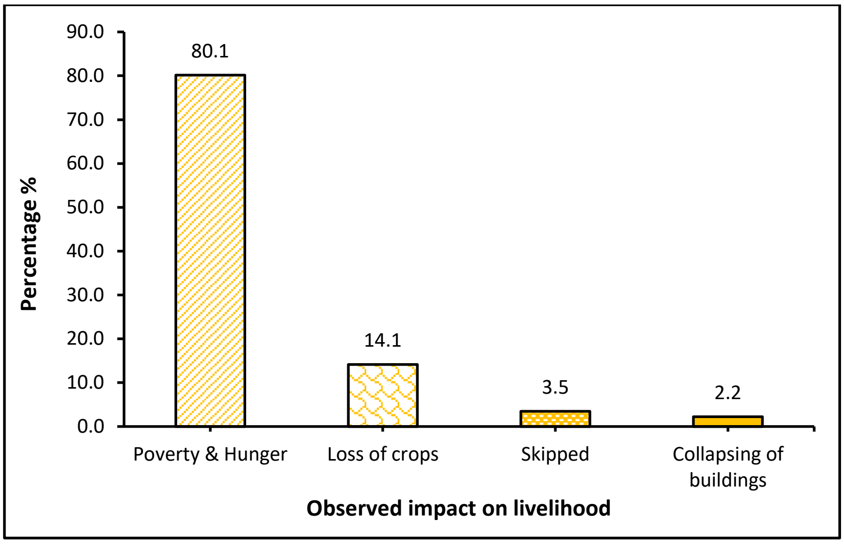


Figure 3.7: Description of effects of observed climatic change impacts on farmers' livelihoods in two agro-ecological zones in northern Ghana.

Other farmers (14.1 %) mentioned poor yields or total loss of crops, either from excessive rainfall or delay in the onset of the rains, or the shortened duration with longer drought periods. Also, 2.2 % of farmers asserted that the highly intense rainfall with its accompanying thunderstorms cause collapsing of buildings aggravating their poor economic state. Consistent with findings of Azongo et al. (2012), which indicated that northern Ghana frequently heavy rainfall and flooding during the peak of rainy season, often resulting in destruction of homes displacement of families.

Findings from the discussions on observed climate impacts were consistent with the responses from the quantitative phase (Figure 3.8). Majority of the discussants explained that the changes in pattern, duration and amount of rainfall negatively affects their production, as production is mostly rain-fed, with few crops such as rice cultivated under irrigation in the Sudan agro-ecological zone where the irrigation facilities exist. Listed in figure 3.8 below are the numerous effects of climate change on their livelihoods, grouped under three headings, farming activity, environmental and economic impacts consistent with findings from the quantitative phase.

Farming activities

- Poor yields.
- Partial or total loss of crops.
- Increased cost of production.
- Increased disease and pest infestations.
- Poor soil conditions.

Environmental

- Flooding leading to the distruction of lives & property.
- Insufficient water for plant growth & domestic use.
- Increased temperatures.
- Long drought.
- Increased bushfires.

Economical

- Food shortage and hunger.
- Reduced income.
- High cost of inputs (high demand).
- Cost of repairing of damage caused by floods.
- Deepening poverty.
- Poor pricing of produce at the local market

Figure 3.8: List of climate impacts on livelihood from farmers' points of views under 3 headings: farm activities, environmental and economical in two agro-ecological zones in northern Ghana.

Most discussants from the Sudan zone, for instance, lamented that farm yields continue to decline despite their best efforts, comparing their farm sizes to their predecessors, who they say cropped smaller farms with higher yields and superior quality produce as mentioned below by a male discussant from the Sudan zone. *"We have increased our farm size, and yet the yield is low with poor quality produce."* This is consistent with IPCC (2014) and Schlenker and Lobell (2010) reports which predicted climate variability and change to continue to decrease the agricultural production of major cereal crops in sub-Saharan regions, including maize, sorghum and millet, the major crops grown by the discussants. The statement, however, prompted another discussant to attest that the situation is due to excessive use of inorganic fertilizer and pesticides, resulting in low yields and poor-quality produce.

Findings also showed that the irregular pattern of rainfall makes it difficult to plan the farming season, as it affects the onset and cessation of rainfall leading to a change in the cropping systems and consequent changes in dietary requirements. The changes in cropping systems showed that certain crops have been dropped due to either the delay in the onset of the rains or the shortened rainy season leading to a shortened cropping season. For instance, discussants in the Guinea savanna zone stated that guinea corn has been dropped from the system due to the shortened rainfall patterns. They explained that the traditional cultivars they grow require over three months to mature, while the shortened rainy season barely extends to three months. Cassava has therefore replaced yam cultivation since it can withstand the reduced soil moisture. *"We are cropping more cassava than yam, since they are doing well requiring less amount of soil moisture more than yam."* A male discussant, Guinea savanna zone.

In the Sudan savanna zone, early millet was dropped due to the delay in the onset of the rainy season. Early millet is planted at onset of the first rain and harvested during the brief dry spell lasting about six weeks within the rainy season. However, the increasingly shortened rainfall pattern has made it impossible to cultivate early millet within this window. As described by a female discussant from Guinea savanna FGD: "*The rains deceive you to sow early, but a long dry spell follows it, resulting in 'death' of the seeds because of insufficient soil moisture"*

The discussants pointed out that poor seed germination or total failure due to insufficient soil moisture requiring partially or full resowing of field add to the increase in cost of production since excess seeds is needed for sowing indicated by a female discussant above.
Also, the uncertainty of onset of the rain meant farmers depend on animals or tractor-driven ploughs for land preparation to quickly prepare the field instead of manual labour, another cost component brought about by climate variabilities.

Furthermore, most of the adopted hybrid seeds or improved cultivars, especially maize, do not do well without inorganic fertilizer. Thus, there has been an increased use of inorganic fertilizer, adding to the cost of production, coupled with the cost of pesticides used to control pest infestations. The quote below expresses the view of a male key informant from the Guinea savanna zone: *"Smallholder farmers are not farming due to the increase in production costs, especially this farming season."*

Increased in the incidence of disease and pests in addition to poor soil conditions mentioned by the discussants as caused by climate impact, is resulting in reduction in yields and poor quality of produce from farms. According to the discussants, this has led to a decline in the seasonal income that they generate from sales of excess produce from farms, after storing what was to be used to feed their families. They explained that feeding their families is even becoming difficult, as the impact has caused changes that are either preventing them cropping sufficiently or harvesting less than required for family use.

3.3.5 Access to weather information

Access to weather information is one of the factors that influences the decision-making of farmers regarding their adaptations to climate change (Ndamani & Watanabe, 2016; Mutunga et al., 2018; Diouf et al., 2019; Marie et al., 2020). The study revealed majority (68.5 %) stating their interest in weather forecast against 31.5 % who had no interest. The farmers revealed several reasons why they show interest in weather information (Figure 3.9). The majority (66 %) used weather information for planning their farm activities, when preparing their land and start planting, and what type of crop to plant, supporting Saguye (2016) and Mutunge et al.'s (2018) findings that access to weather information is a determinant for small scale farmers' adaptation decisions. Also, results from logistic regression models showed that farmers' decisions regarding land management and crop management-related adaptation are influenced by 68 % and 66 %. chance respectively based on availability of weather forecast information. Thus, farmers' decisions on land and crop management adaptation are made based on the weather information available to them whether traditional or scientific. Meanwhile, some of the 20 % of farmers who stated media or language barriers, explained that they do not have access to information on weather forecasts because they do not have radio or television sets. Likewise, Muema et al. (2018) evidenced that television ownership increased the likelihood of accessing and using climate information services. Mabe et al. (2014) and Khan et al. (2019), found that access to mobile phones influences adaptive choices by smallholder households. Others stated that they are uneducated and therefore do not understand what is said in English during the televised weather forecasts.

The 6 % of farmers that indicated unreliability of forecast information explained that they do not trust information provided during forecasting, since predictions were incorrect most times. Likewise, findings by Serra and Mckune (2016) indicated that the lack of trust and unreliability hinders the use of climate information for climate change adaptation.

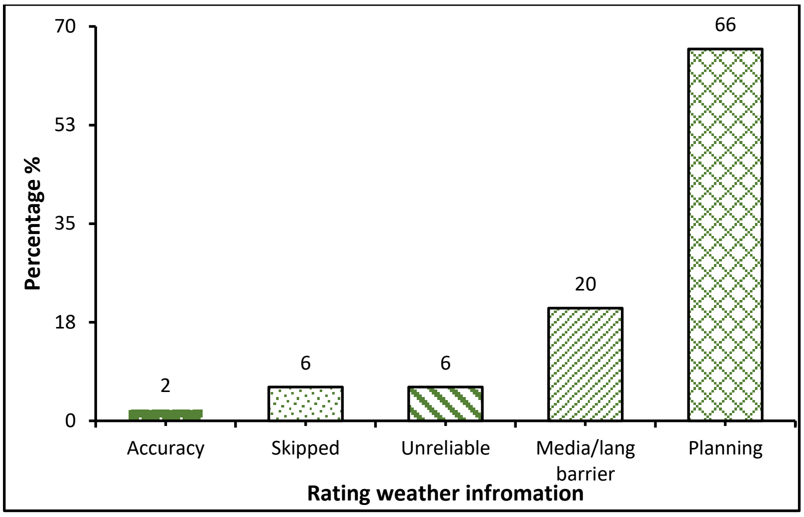


Figure 3.9: Description of farmers' reasons for interest in weather information in two agro-ecological zones in northern Ghana

The remaining 2 %, on the other hand, stated that the information shared during forecasts is accurate, making them capable of planning their farming activities. This is consistent with Mudombi and Nhamo's (2014) assertion that information should be reliable, trusted, and understandable for farmers to use. Radio (Table 3.3) is the most used medium for weather information among the farmers (69.2 %). This is consistent with Tun Oo et al.'s (2017) findings that information from radio affects the choices for adaptation strategies, followed by television (20.8 %), mobile phone (4.5 %), and downloaded weather apps (0.7 %), while 22.6 % farmers indicated none.

Table 3.3: Description of farmers' preferred weather information type and medium of delivery in two agro-ecological zones in northern Ghana

Medium	Percentage	Weather information type	Percentage
Radio	69.2	Daily temperature	70.0
Television	20.8	Rainfall date and amount	24.8
Mobile phone	4.5	Precipitation	11.7
Weather App	0.7	Sun intensity	9.7
None	22.6	Windspeed	2.7

These may be farmers who indicated no interest in weather information. The result also revealed that 74.6 % of farmers in the Guinea savanna zone use radio, compared to 63.7 % farmers in the Sudan savanna zone, while 30.9 % farmers in the Sudan savanna used television, compared to 11.0 % farmers in the Guinea savanna zone. These differences may be the result of the recorded difference in education between the two zones, since most local radio stations broadcast in local dialects, a factor revealed by Hampson et al. (2014) and Oyekale (2015) on the use of vernacular language as one of the reasons for the high access to information via radio. As such, 67.7 % farmers from the Guinea savanna zone with low or no education preferred radio (in local dialect), while highly educated farmers. (79.1 %) from the Sudan savanna zone opted for televised broadcasts presented in English. Anang et al. (2020) reported that low level of education among the farmers could have significant implications on their human capital development and their ability to take advantage of opportunities and production technologies to improve farm performance. While Uddin et al.'s (2014) asserted that farmers with higher levels of education tend to have greater access to information than those with a lower level of education.

However, (Mbanda-Obura et al., 2017; Maguire- Rajpaul et al., 2020; Popoola et al., 2020; Baffour-Ata et al., 2022; Awuku-Manteaw, 2022), reported that apart from radio and television, rural farmers rely on information from family members, and neighbouring farmers as their basic sources. According to Nawab et al. (2020) attested that as varied are the information needs of smallholder farmers, so are their sources of information.

3.3.5.1 Type of weather information accessed

When asked about the type of weather information received, 70 % of farmers stated daily temperature, followed by rainfall date and amount (24.8 %) consistent with finding from (Lebel, 2013; Mudombi & Nhamo, 2014; Shackleton et al., 2015; Antwi-Agyei et al., 2021c; Baffour-Ata et al., 2022) which is vital for prior planning of the season. Furthermore, 11.7 % mentioned precipitation, with 9.7 % citing sun intensity and 2.7 % stating wind speed (Table 3.3). The receipt of weather information for daily temperature, rainfall date and amount and sun intensity were significantly different between the zones using the Chi-Squared test (X^2 = 56.403, 10.259, 17.614; df=1; p=0.001; p=0.001; p=0.001; p=0.001, respectively).

A total of 175 farmers in the Sudan zone compared to 107 in the Guinea zone received information on daily temperature, while 64 in the Guinea zone received information on rainfall date and amount versus 36 in the Sudan zone. Lastly, 7 farmers in the Sudan zone received information on sun intensity compared to 32 farmers in the Guinea zone. However, the receipt of information on precipitation and wind speed was not significantly different statistically ($X^2 = 1.527, 0.088$; df= 1; p=0.217, 0.766, respectively).

3.3.5.2 Preference for weather information delivery

According to Nyadzi et al. (2019) and Gbangou et al. (2019), weather information delivery must be timely for effective use in seasonal decision-making by farmers. Using a percentage probability score derived from re-scaled scores, the mean weight is subtracted from each item and then re-scaled by multiplying each score by a multiplier up to 100. The resultant value reflects the likelihood of items being selected within the questionnaire. Thus, an item with a score of twenty is twice as important (or preferred) as an item with a score of ten.

The logistic model (Figure 3.10) shows that farmers preferred daily weather information delivery (highest probability of 25.50), and this concurred with findings by Hampson et al. (2014), which showed that most farmers stated daily forecasts in Tanzania. Monthly weather information delivery followed with percentage probability of 24.65 and the yearly forecast was rated the worst (probability of 14.68). However, literature indicates that seasonal weather information delivered at the onset of the planting season in other countries (Ingram et al., 2002) enables farmers to plan when to start the season's activities, such as changing planting dates if required, based on the information available.

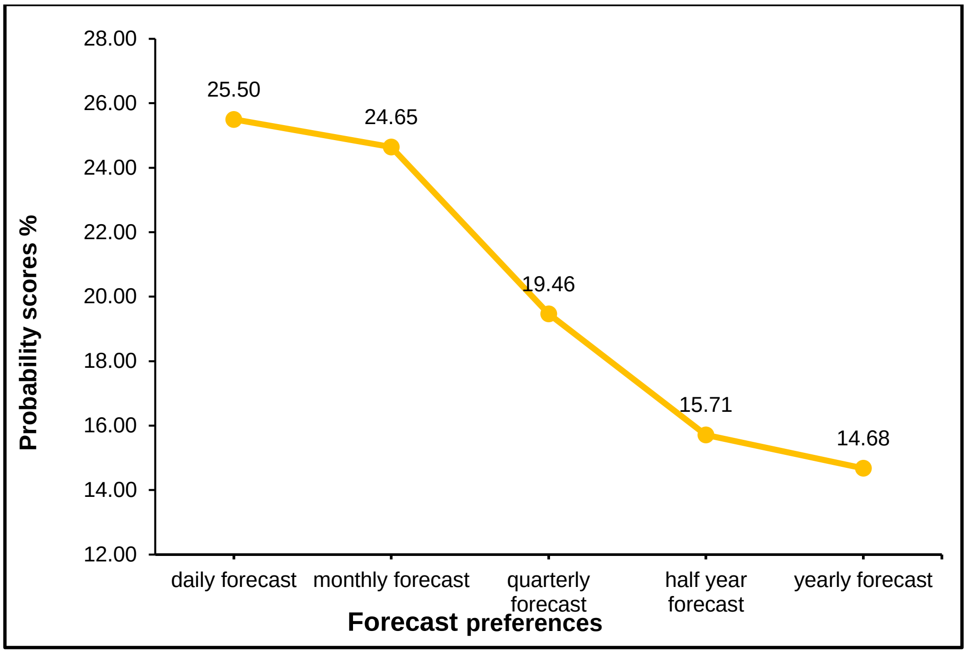


Figure 3.10: Description of farmers' preferences of weather delivery using probability scores in a MaxDiff logit model in two agro-ecological zones in northern Ghana.

In answering what method, they prefer to use for their weather information, whether scientific or traditional, 106 farmers in the Guinea zone use scientific methods, compared to 56 farmers in the Sudan zone. Moreover, 89 farmers use traditional methods in the Sudan zone versus 38 in the Guinea zone. This is consistent with findings from Jiri et al. (2016) in South Africa, which indicated that most smallholder farmers use traditional climate indicators for short-term critical farm decisions, which was also highlighted by Rankoana (2016) and Ubisi et al. (2017). Some of the farmers (57) in the Guinea zone indicated combining both methods, compared to 55 in the Sudan zone.

3.3.6 Traditional mode of weather prediction

To understand how traditional weather forecast information is used in adaptation by discussants, the findings from the first phase were used as a premise for the discussions during the interactions. It was surprising to state that most participants did not have much knowledge about interpreting the weather, making one wonder how they have been managing their farms up to now.

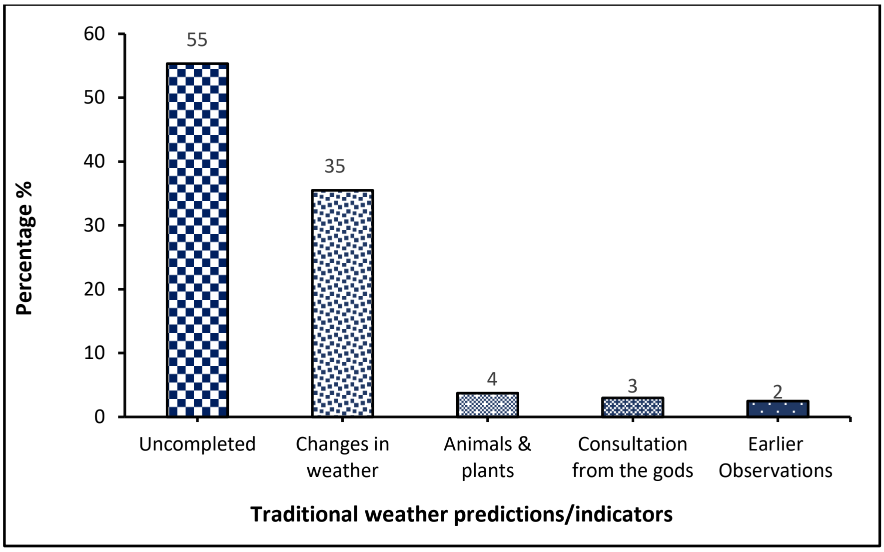


Figure 3.11: Description of percentage of farmers that use traditional weather predictions and their indicators in two agro-ecological zones in northern Ghana.

Most (55 %) farmers did not complete the form on traditional weather indicators (Figure 3.11), however, 35 % of farmers indicated the use of traditional methods for weather information. They mentioned their predictions are based on changes in weather pattern, consistent with Gyampoh and Asante's (2011) findings in southern Ghana about using weather patterns in predictions. For instance, strong heat intensity in February and March signifies heavy rains in the coming season while weaker heat intensity means a poorer rainy season.

Likewise, 4 % stated the use of certain animals and plants to predict weather changes (Figure 3.11), concurring with Sullo et al.'s (2020) findings of the use of 'populs 'plant and insects chirping as indicators of excessive heat, and the movement of millipedes as an indicator of an approaching season or sudden change in climate. Still, 3 % of the farmers stated that they consult the gods for the prediction of weather, and the least (2 %) use their previous observations based on their experiences to predict weather for planning the season.

In confirmation, most discussants did not have much knowledge about predicting and interpreting weather using traditional methods, as depicted in the 55 % of farmers who did not complete the section of the questionnaire. Those from the focus group and key informants mentioned the use of certain animal and plant behaviours, the performance of rituals by rainmakers to the 'gods', and natural phenomena. However, contrary to the 3 % that consulted the gods, they indicated that ritual performance is no longer performed due to religions (e.g. Christianity and Islam) and modernisation that frown on it. They further explained that younger generation do not want to be involved in such practices even though they may not be religious.

Most of the elders interviewed were silent about any religious engagements (ritual aspect and performance). A few of them said the younger generation had no interest in it and are not willing to even listen to the stories let alone put it into practice. Very few (2/8) ascribed the variable state of the weather to the anger of the gods for breaking traditional norms. Table 3.4 described some of the traditional indicators used by the respondents under four headings namely symbol, signs, status in terms of use as explained by interviewees:

- Signalling = currently still in use as signals for planning farm activities.
- Not-signalling = not in use since signals always give contrary outcome when used.

For instance, signals for morning dew are no longer in use since the phenomenon no longer occurs due to increase in nighttime temperature according to respondents supporting references from literature.

Table 3.4: Description of traditional indicators used by farmers in two agro-ecological zones of northern Ghana for weather predictions and their status by respondents with references from literature.

Local Indicators	Signs	Status according to the respondents	Similar literature references
Indicators from certain Plants species			
Certain tree type in the bush (no name given)	Sheds its leaves at the beginning of the rain and used to predict the onset of the rainy season.	Signalling	Ayal et al. 2015; Sullo et al. 2020
Raspberry tree	Heavy yields of the raspberry plant indicate irregular rainfall pattern in the following season.	Signalling	Ifejika Speranza et al. 2007; Baffour Ata et el. 2021.
Type of plant (local name = Brensu) in the bush	Heavy yield means heavy rainfall for the next season.	Signalling	Kagunyu et al., 2016; Jiri et al. 2015
Raspberry and baobab trees	Flowering signifies the beginning of the rainy season	Signalling	Orlove et al. 2010; Sumi 2018; Baffour Ata et el. 2021.
Indicators from certain Animal species			
Upland frog	Intensive croaking signifies rains	Partially Signalling	Muguti & Maposa 2012; Radeny et al. 2019.
Black and white Mannkin (native bird) in the forest	Persistent cries indicate cloud formation and heavy rainfall	Signalling	Muguti & Maposa 2012; Radeny et al. 2019; Sullo et al. 2020
Indicators from Weather Phenomena			
Movement pattern of a particular morning star	Change in the movement pattern of the star indicates change in the season from rainy to drought/drought to rainy seasons.	Partial Signalling	Radeny et al. 2019; Irumva et al. 2021
Very bright sky	Excessive brightness of shining sky indicates the onset of rain	No longer Signalling	Muguti & Maposa 2012; Irumva et al. 2021
Sun intensity	High intensity of the sun, extremely hot, making the body prick signifies the rains will fall	No longer Signalling	Gyampoh 2009; Muguti & Maposa 2012; Irumva et al. 2021
Wind direction	When the wind blows towards the west around May, it signifies the near arrival of rain	No longer Signalling	Gyampoh 2009; Orlove et al. 2010; Irumva et al. 2021
Cloud formation	Dark clouds formed from the east indicate rain will fall	No longer Signalling	Gyampoh & Asante 2011; Mugambiwa 2018.
Morning dew	A lot of dew in the morning indicated no rain	No longer Signalling	Ifejika Speranza et al 2007; Radeny et al. 2019.

3.3.7 Capacity-building of smallholder farmers

3.3.7.1 Training received by farmers

Training and advisory services are provided to farmers to build their capacity and introduce modern technologies, disease, and pest control mechanisms, as well as policy information, etc., to ensure maximum production and yields. This training and service delivery in developing nations is mostly done by public agriculture extension agents (Anang et al., 2020). Most farmers (74.9 %) in the study area did not attend any training within the last 5-year period, with just 25 % receiving some form of training. Of the 101 farmers who attended training, most (87) received training in proper use of inorganic fertilizers and 84 farmers were trained in farm management practices, respectively (Table 3.5). Furthermore, 73 and 18 farmers received training in the introduction of modern technologies (new seeds for planting for any of the crops grown, resistant varieties, fertilizer) and marketing idea development, respectively. The farmers that said they had no training (302) did not complete the section of the questionnaire. Some of the farmers also indicated no for the type of training received (Table 3.5). Consistent with Angello (2015), Sebeho and Stevens (2019) and Anang et al. (2020)'s findings that public extension contributes to most training in developing nations, most (19.4 %) of the training was organised by public extension officers, followed by 12.2 % by NGOs, and 4.7 % by farmer groups.

Most focus group discussions confirmed engagement with public extension officers but not regularly. Some farmers indicated as long as six years ago as their last interaction with an extension officer consistent with Akpotosu (2017) and Anang et al. (2020)'s assertion that public extension services lack resources to regularly engage farmers. While the most recent interaction was over a 2-year period both for farm and off-farm activities and advice. For instance, in the Guinea savanna zone, the farmers were introduced to the cultivation of tree crops (oil palm and mango).

Table 3.5: Frequency and percentages of training received, offering agency, type of training, group membership and type of groups used by farmers in two agro-ecological zones in northern Ghana.

Farmers' Participation Options	Category	Frequency	Percentage
Training attended			
Agriculture training received within the last 5-year period	Yes	101	25.0
	No	302	74.9
	Total	403	100.0
Agricultural extension officers offered training	Yes	78	19.4
	No	23	50.7
	Uncompleted	302	74.9
Non-governmental organisation offered training	Yes	49	12.2
	No	52	12.9
	Uncompleted	302	74.9
Farmer group organised training	Yes	19	4.7
	No	82	20.3
	Uncompleted	302	74.9
Type of training attended			
Farm management training	Yes	84	20.8
	No	16	4.0
	Uncompleted	302	74.9
Introduction of new technologies: new hybrid seed for sowing, resistant varieties	Yes	73	18.1
	No	27	6.7
	Uncompleted	302	74.9
Proper use of inorganic fertilizers	Yes	87	21.6
	No	13	3.2
	Uncompleted	302	74.9
Marketing idea development training	Yes	18	4.5
	No	82	20.3
	Uncompleted	302	74.9
Member of farming association and type of association			
Member of any group	Yes	66	16.4
	No	337	83.6
	Total	403	100.0
Production group	Yes	36	8.9
	No	30	7.4
	Uncompleted	302	74.9
Credit association	Yes	14	3.5
	No	52	12.9
	Uncompleted	302	74.9
Agro processing group	Yes	12	3.0
	No	54	13.4
	Uncompleted	302	74.9
Marketing group	Yes	6	1.5
	No	60	14.9
	Uncompleted	302	74.9

Mutual labour support group	Yes	47	11.7
	No	19	4.7
	Uncompleted	302	74.9
Welfare service support group	Yes	17	4.2
	No	49	12.2
	Uncompleted	302	74.9

3.3.7.2 Membership of farmers 'groups

Being part of farmer groups is beneficial for farmers to share information and expertise on farming activities, capacity-building, and help improve livelihoods by boosting market access and bargaining power. (Qiao et al., 2018; Ahmed & Anang, 2019; Othman et al., 2020). Since farmer groups are voluntary organisation, participation is voluntary, but not all farmers are likely to join as seen in the findings despite it being beneficial for smallholding farmers. While decisions to join depends on farmer's perception of gains to be achieved from participation (Ahmed & Anang, 2019). However, results showed only 16.4 % of the farmers were members of farming groups while 11.7 % belonged to a mutual labour support group (Table 3.5). Also, 8.9 % were in the production group and the least (1.5 %) in the marketing group.

3.3.7.3 Benefit from training

The study showed that most respondents (72.7 %) either skipped the question or stated no benefits from training since they had already indicated that they had not attended any training (Figure 3.12).

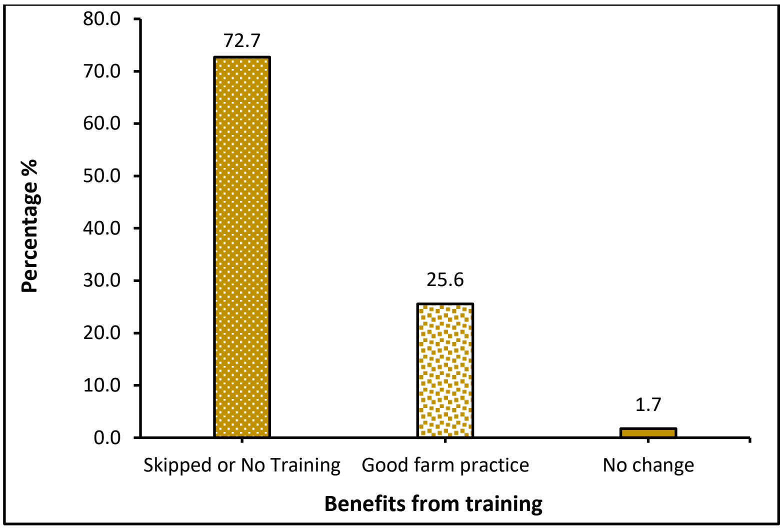


Figure 3.12: Description of farmers perceived benefits from training received within 5- year period in two agro-ecological zones in northern Ghana.

However, 25.6 % of those who received training reported benefits in improving agronomic practices such as improved fertilizer application, introduction of new crop varieties, planting methods, proper application of chemicals on crops, crop type selection and proper farm management practices. Conspicuously missing is the access and use of weather information for decision-making. Still, 1.7 % of the farmers indicated that they are yet to see benefits from the training. The focus group mentioned similar benefits gained from group membership such as loan acquisitions for farming activities and reductions in labour costs, as members tend to support each other especially at the beginning of the farming season.

3.3.8 Logistic regression analysis result

Result of two logistic regression based on crop and land managements related adaptation (Tables 3.6 a&b) showed that farmers' decisions on both crop and land management adaptation is influenced between 66 % – 68 % by their access to weather forecast through either scientific or traditional means. Consistent with studies that showed that farmers use weather forecast on rainfall and temperature for adapting to climate variations through prior planning of farming activities (Lebel, 2013 in Asia; Mudombi & Nhamo, 2014 in South Africa, Shackleton et al., 2015 in Europe; Baffour-Ata et al.,2022 and Agyekum et al., 2022 in Ghana).

Also, perceived or observed weather change by farmers has a probability of 82 % influence on crop management adaptation choices likewise to Owusu et al. (2021) findings in three agro-ecological zones of perceived long drought with shortened farming seasons and adapted by growing early maturing maize.

Table 3.6a: Logistic Regression Models: Crop management related adaptations showing parameter under consideration (bold font) that influence farmers' farming decisions in two agro-ecological zones in northern Ghana.

Variables	Exp (B)	Probability	95% CI	P-value
Weather forecast	**1.94**	**0.66**	**1.071–3.513**	**0.03****
Crop techniques	2.04	0.67	1.514–2.759	0.00***
Gender	0.29	0.23	0.135–0.638	0.00***
Level of education achieved	0.49	0.33	0.255–0.933	0.03**
Constant	1.24			0.00***

N = 401

Nagelkerke R Square = 0.558
Chi-square = 11.4
Significance level= 0.18
2 Log likelihood = -328.060
Overall correct prediction = 82.3%

*** p<0.01, ** p<0.05, * p<0.1

Table 3.6b: Logistic Regression Models: Land management related adaptations showing parameters under consideration (bold font) that influence farmers' farming decisions in two agro-ecological zones in northern Ghana.

Variables	Exp (B)	Probabilities	95% CI	P-value
Observed/perceived weather change	**4.45**	**0.82**	**1.261–15.707**	**0.02*****
Years of practicing technique	0.69	0.41	0.51 – 0.93	0.01***
Weather forecast	**2.13**	**0.68**	**1.25 – 3.61**	**0.01*****
Gender	0.60	0.38	0.36 – 1.01	0.05**
Constant	3.59			0.00***

N = 403

Nagelkerke R Square = 0.301
Chi-square = 10.96
Significance level= 0.204
2 Log likelihood = -417.60
Overall correct prediction = 73.3%

*** p<0.01, ** p<0.05, * p<0.1

3.4 Discussion

Farmers' perceptions and observations of climate change in their respective agro-ecological zones play a key role in shaping seasonal farming decisions. These perceptions influence their ability to adapt to climate variability, prompting transformations in farming systems that support sustainable agricultural production and livelihoods. Climate change, driven by global warming has led to more frequent extreme weather events and hazards that negatively affect livelihoods and human well-being (Ma et al., 2018; Gentle & Maraseni, 2012; Debela et al., 2015; Apanga et al., 2017). In Africa, the agricultural sector is especially vulnerable due to both environmental and socio-economic factors (Yaro, 2013; Abebe et al., 2018). Smallholder farmers face a range of hazards, including land and soil degradation, drought, and erratic rainfall, which threaten crop yields and rural livelihoods (IPCC, 2014b; Derbile & Laube, 2014). Without appropriate on-farm adaptation strategies and support, climate change will likely continue to undermine food security and deepen poverty. Understanding farmers' perceptions, their adaptive responses, and the barriers they face is crucial for developing effective strategies to address the impacts of climate change on smallholder agriculture (Acquah, 2011).

3.4.1 Observed or perceived climate change variations

Smallholder farmers perceived or observed changes in weather conditions due to climate change have been recorded to impact planning and farming choices in coping or adapting to climate variations and impact on farming output. Farmer's perceptions on climate variations varies in accordance with literature (IPCC, 2014b; Metag et al., 2017; AValéria et al., 2020). This is shown as responses to certain seasonal climate events such as length of the dry period, intensity of the rain, and its duration are impacting negatively on crops differently resulting in variation in yields. There is therefore the need for adjustment of crop and land management practice appropriate to reduce the risk of crop failure in enhancing adaptive capacity of the farming alongside the socio ecological systems to withstand climate shocks that may negatively affect livelihood. As literature suggested, there is the need to tailor adaptation strategies for climate impacts to ensure success using social learning through coproducing of knowledge from diverse stakeholders and knowledge sources (Srivastava et al., 2016; Partey et al., 2018).

3.4.1.1 Changes in temperature

The record of a perceived reduction in temperature in both agro-ecological zones during the quantitative phase consistent with empirical evidence from Ayal and Leal Filho (2017) and Owusu et al. (2021) that certain aspect of smallholder farmers' perception of climate change was inconsistent with meteorological data. This makes the findings important since smallholder farmers' activities are plans based on their perception formed interacting with their environment. However, different farmers' interpretations of observed situations may differ resulting in different adaptation choices since perception is influenced by many factors (Capstick, 2018; AValéria et al., 2020).

Findings of the study showed that 82.0 % of farmers' land management related adaptation is influenced by observed and perceived weather variations. A projected 1.5^0 C increase in temperature is expected to cause a 9 % decline in maize yield in West Africa (WMO 2022). To successfully adapt to climate change, farmers need access to reliable weather information, derived from TK or scientific sources to guide the adoption and use of appropriate technologies for successful adaptation to climate change. Yet, there is often a mismatch between available information and what is needed to support on-the-ground decision-making (Antwi-Agyei et al., (2021c), though farmers have proven their ability to manage their daily difficulties and make the most of available resources. The lack of suitable information often weakens farmers' managing abilities, leading to conflicting perspectives and poor decisions on adaptation choices (Anatolie et al., 2021). This could further increase the existing deficit of adaptive capacity of smallholding farming systems, making them more vulnerable to climate variations that could inhibit resilience building and sustainability of smallholder farming livelihoods.

High temperatures contribute to water stress in crops, inhibiting their development and ultimately reducing yields. To maintain productivity under such conditions, farmers must adopt crop varieties that are resilient to rising temperatures. Thus, making decisions based on inaccurate or unreliable information can severely undermine the productivity and resilience of smallholder farming households, particularly as they face increasing climate variability (IPCC, 2014).

Most focus group discussants, especially women, noted that elevated temperatures have made daily tasks more difficult and disrupted sleep at night, resulting in poor rest (Figure 3.8). This aligns with studies showing that heat stress negatively affects outdoor workers like smallholder farmers (Pogačar et al., 2017; Al-Bouwarthan et al., 2019; Mansor et al., 2019; Frimpong et al., 2020). Prolonged exposure to high temperatures during agricultural activities, as the study showed, can lead to mental, physical, and psychological health issues (Frimpong et al., 2020). Tasks such as seedbed preparation, planting, weeding, and harvesting now take longer due to slower work pace under extreme heat. Additionally, farming hours have decreased, as daily temperatures peak faster, causing early fatigue. Although individual tolerance varies, all respondents acknowledged a loss of labour time, reducing productivity. The combination of extreme heat, reduced work capacity, and health risks ultimately lowers yields and income, undermines food security, and deepens poverty among smallholder households.

Furthermore, dry season farming relies heavily on irrigation, primarily using water from boreholes and dams. Due to extreme heat, only farmers with high heat tolerance can participate in off-season farming making it more profitable because of reduced competition and higher market prices. However, rising temperatures are reducing the number of farmers able to farm during this period, leading to lower food production for both household consumption and sale. This challenge is compounded by annual blue water scarcity, limited surface and groundwater availability, particularly in northern Ghana during the dry season (Asante & Amuakwa-Mensah, 2014; Water Footprint Network, 2018).

3.4.1.2 Changes in rainfall patterns

The results showed that farmers perceived uncertainty in rainfall in terms of the onset of rains in the raining season, variabilities in the onset of rains in the raining season, cessation of rains, drying period within the farming season, length of rainy days and number of dry days - consistent with previous studies (Antwi-Adjei et al., 2021; Omay et al., 2023).

The difference in farmers' responses across the agro-ecological zones concerning their observations of weather parameters such as drought period, rainfall patterns and intensity, reduced soil moisture, and temperature changes may have been shaped by a range of influencing factors such as social, institutional, cultural, or psychological elements

(Leiserowitz, 2005). Undoubtedly, it still supports the concept that effects of climate changes differ from one agro-ecological zone to another, thereby requiring different adaptation strategies (IPCC, 2014b; Ingram et al., 2016). However, parameters such as irregular rainfall patterns, increase in temperature and decrease in rainfall intensity were observed equally by farmers between the agro-ecological zones (Karki et al., 2020; Ngute et al., 2021).

The onset of rains, length of rainy days and cessation of rainy season have impact on crop production (Gedefaw et al., 2018; Karki et al., 2020). For instance, with the onset of the rainy season quoted as starting in May in the Guinea savanna zone, unlike previously in March, it means more drier days, during which farmers must rely on previous produce to feed the family. Also, the delayed onset of the season puts pressure on land preparation and sowing, as everyone will be clamouring for the limited inputs needed for the start of the season, and as demand increases, cost increases. Help from other farmers, for example, will be difficult to solicit, and farmers must depend mostly on family members which limit the farm area cultivated as benefits as reported by Ahmed and Anang (2019) from mutual groups are lost. The irregularity of the onset of the rain adds to the farmers 'plight, as they are not able to predict the start of the season based on the previous year's rainy season for decision-making, resulting in ad hoc planning.

While the number of rainy days affect flowering and filling of cops/ears of cereals, farmers have to time sowing such that these periods of crop development coincide with rainy days to ensure required yields (Yang et al., 2019). Also, the cessation of rains affects crop maturity and harvesting, beyond which crops in the field are prone to diseases and loss of yield. Majority of the focus group discussions revealed loss of soil fertility through the loss of top-soil due to the increased rainfall intensity within a brief period, causing extra work in terms of activities to improve soil fertility that adds to the cost for production.

Thus, farmers' decision-making processes have become more complex due to climate variability and impacts. This situation paves the way for policies that can introduce recent technologies for adoption as the fast-changing situation keeps eroding the traditional indicators faster than farmers could process and assign new signs or symbols to feed into the decision-making processes. For instance, the promotion of access and proper use of information technology (e-agriculture) by smallholder farmers would enhance access to appropriate and timely information on weather conditions which are one of necessary conditions among others for increased productivity (Ponge, 2016).

3.4.2 Factors contributing to changes in weather pattern

The study revealed that farmers were aware of the causes of climate changes, most mentioning human activities that are harmful to the environment. This is consistent with the extensive literature affirming that climate change is human caused (anthropogenic). Respondents stated activities such as deforestation without mentioning the use of fossil fuels that contribute the most to CO2 emissions consistent with findings from Yamba et al. (2019). Some of the farmers (21%) stated that natural disasters are the cause of the changing weather patterns. Many of the farmers indicated that they have experienced decades of natural changes in the environment, which always allowed them to adjust their practices while learning to build adaptive capacity to these changes gradually. But human-made climate change phenomena are different, and farmers will need more time to gradually study and adjust to its rapid impacts. Local communities need education on climate change and its projected impacts on their environment and livelihoods. Sharing information can foster social learning leading to behavioural and cultural changes. This combined with access to appropriate technologies could enhance adaptive capacity which may lead to the resilience of both farming systems and the local economy. Education on climate change will also enable the few farmers (11.2 %) who attributed the causes to religious and cultural belief to understand better the underlying mechanisms of climate change impact. The state of uncertainty for the future that local communities are experiencing require policy interventions that will create room for social learning and coproduction of knowledge using multiple stakeholders with the aim to transform the society to become more resilient to changing weather (Durose et al., 2017; Church et al., 2022).

3.4.3 Climate change impact on smallholder livelihoods

Although African countries contribute only 3.8 % of total greenhouse gas (GHG) emissions (UN, 2011; WMO, 2022), research has shown that they will experience early and greater impacts than other continents due to weaker resilience in farming system with reduced adaptive capacity, and greater dependency on environmentally sensitive sectors such as agriculture.

3.4.3.1 Impact on the economy

The results revealed that farmers have experienced climate change impacts over the last decade, consistent with literature that predicted early climate impact on smallholder farm productivity. Most respondents (81.1 %) described deepening poverty and hunger. Consistent with literature findings that specify climate change would worsen the already dire poverty conditions of African smallholding families when compared to other continents (FAO & ECA, 2018; Trisos et al., 2022). For instance, the FAO (2018) report indicated that hunger is worsened in countries with agricultural systems sensitive to climate variability and high livelihood dependence on agriculture as in Ghana. FAO (2022) also reported an increase in the estimated population of the world's under-nourished, and food deprived from around 806 million in 2016 to almost 851 million in 2017.

Although Ghana's situation has not reached the status of a chronic food-deprived state, with the rate of increase in climate change and extreme conditions, the threat of smallholder farming families ending up in such a situation is more realistic. With low yields and long dry periods, families must depend on almost non-existent stored food until the next crop season produce is harvested, leading to a vicious cycle. For instance, FAO (2015 a&b) and Stuch et al. (2021) showed that maize and tropical cereals (sorghum and millet) are the dominant crops for food security in sub-Saharan Africa. As they cover about 73 % of the harvested grain producing areas and are widely spread across varying agro-climatic areas within the region (Singh & Singh, 2017).

The findings also noted that they contribute about 86 % (maize) and 88 % (tropical cereals) production to food availability and demand in the sub-Saharan African region with only 0.6 % maize and 0.3 % tropical cereals exported from the region emphasizing the importance of these cereals to food security in the region. However, with changing climatic conditions predicted to affect the yields of these crops, sub-Saharan Africa including Ghana, faces food security threats for which governments need to develop policy interventions for adaptation and prevention through social learning and capacity building.

Agriculture is still the main stay of Ghana's economy that employ 44.7 % of workforce of which majority practice smallholding in food crop production (Dwamena et al., 2022). Also, smallholding production accounts for about 80 % of Ghana's agriculture output and 28 % of the gross domestic product (Ofori-Sarpong, 2001; Baidu et al., 2017). Thus, if Ghana is to achieve its SDGs in eradicating poverty and hunger and achieving economic growth, then resilience of smallholding food production systems must be enhanced to withstand climate impact and increase productivity. Through the provision of access and use of agricultural innovations using combined knowledge since smallholding production fuels rural as well as the general economy.

3.4.3.2 Impact on farming activities

The study revealed that farmers experienced a range of negative impacts due to climate variability, including poor yields, increased pest and disease infestations, and declining soil fertility, largely driven by extreme weather events such as floods and high winds (Figure 3.8). These findings align with existing literature indicating that temperature and rainfall increases have reduced cereal yields by 10–20% for maize and 15% for rice (Nelson et al., 2009; Thornton, 2012). Farmers' frustrations echoed in Thornton's (2012) findings, which show that while some crops tolerate higher temperatures, they remain highly sensitive to rainfall variability. Additionally, crops that withstand flooding may become more vulnerable to pests and diseases, and even disease-resistant varieties can struggle when night-time temperatures rise.

This growing complexity in agricultural decision-making has made smallholder farming increasingly difficult. Farmers are now required to make more frequent, informed decisions to maintain productivity and secure their livelihoods. This underscores the critical need for timely access to relevant climate information and resources, a conclusion supported by Yaseen (2016) and Hamooya and Ngoma (2019), who emphasize that information access is vital to agricultural productivity and sustainability.

Climate variability has also led to increased production costs. Smallholder farmers now incur additional expenses for land preparation such as hiring tractors or animal-drawn ploughs to respond quickly to unpredictable rain onset. Declining soil fertility has further pushed up costs, especially for fertilizers. Although fertilizer use in sub-Saharan Africa averages just 17 kg/ha far below the global average of 135 kg/ha (AGRA, 2018), many smallholder farmers cannot afford adequate quantities. Those who manage to apply fertilizer at sowing often cannot afford follow-up applications during critical growth stages like flowering, leading to lower yields, especially in maize production.

Transportation and market access remain significant challenges. Poor road infrastructure increases the cost of moving produce to market, and most farmers, especially women, are forced to sell at the farm gate to intermediaries or in local markets—often at disadvantageous prices. During bumper harvests, farmers lack the means to store, or process produce and must sell quickly at low prices. Intermediaries often exploit this situation, using delay tactics to force lower prices (Orlove et al., 2010; Yaro & Teye, 2019).

Farmers also reported increased use of pesticides to control the rising incidence of pests and diseases linked to climate change. However, many lack access to up-to-date pest and disease information due to limited contact with agricultural extension officers. As noted in the study, 61.4% of farmers could not access farming information online due to language barriers and low literacy levels (Table 3.1). This is consistent with Anang et al. (2020), who highlight how limited education hampers farmers' ability to adopt modern technologies and improve productivity.

To enable smallholders to adapt effectively, there is an urgent need to establish systems that provide accessible services, including climate forecasts, market updates, and agronomic advice. These services must be delivered in local languages and formats suitable for communities with high illiteracy levels (Kidido et al., 2017).

3.4.3.3 Impact on the environment

This study revealed that flooding of farmlands during the rainy season due to the high intensity of rains has become frequent. This causes a total or partial loss of yields, or additional production costs when resowing is done to ensure that loss in yield is minimised if floods recede early. This undoubtedly requires policy interventions such as insurance against the effect of extreme weather conditions, to sustain smallholding farmers' livelihoods consistent with findings from Acquah (2011). The flooding of communities displaces members, and strong winds cause occasional collapse of buildings, resulting in further economic hardship in the communities according to the farmers. As extended family members usually must accommodate and support the displaced families or community members (Hudson et al., 2020; Auliagisni et al., 2022).

Also, the combination of a decrease in rainfall, increase in temperatures, and frequent long drought is leading to a considerable decrease in the flow of water bodies, resulting in water stress in terms of domestic and farm use. For instance, a study of selected rivers in Ghana by Kankam-Yeboah et al. (2013) showed that rivers in the White Volta basin will experience a decline in stream flow of approximately 21.6 % by 2020 and 50.1 % by the 2050s. This disturbance may impede access to potable water and may spark animosity among community members who are already suffering economic hardships (WMO, 2022).

3.4.4 Access and use of weather information

In the wake of climate change effects, climate information has become pivotal in planning - particularly in agriculture, a vulnerable sector as well as a contributor to CO_2 emissions. However, the study revealed that the majority (68.5 %) of smallholder farmers showed interest in weather information and used both traditional and scientific sources in planning their farming activities to adapt to changes in their environment. But there are still some farmers (31.5 %) who had no interest in weather information, although this regard sustaining their livelihood as yields will continue to decline without adaptation strategies specific to climate impacts. These farmers' stances may be interpreted as stemming from lesser understanding of the full effect of climate change due to lack of education on climate change causes and effects in the communities as shown in literature (Anabaraonye et al., 2020; Belay et al., 2022; UNDP News, 2023). This was evident from all the focus group discussions stating there has not been any education in the communities about climate change, its causes, and impacts from experts.

Though, a proportion of farmers (35%) stated that they use weather phenomena and experience in making farming decisions, findings show that these signs are becoming quickly ineffective due to climate effects. For instance, a sign of heavy morning dew phenomenon interpreted as no rain in the Sudan savanna zone is no longer experienced because of an increase in night-time temperatures over the past decade. This has affected the yields of early millet cultivation since the maturity stage depended on the morning dew for its development till harvesting.

Also, section of farmers are becoming skeptical of their own perceptions and predictions of the weather, as revealed by the findings in the rapid erosion of familiar signals used in weather prediction. However, there are still a section of farmers who prefer to use traditional methods in weather prediction. As the study findings showed that 31.6 % of respondents in both zones preferred traditional methods of prediction, though the highest number was in the Sudan savanna zone. One could argue that the situation augurs well for local policy formulation on adaptation to climate change as solutions could be tailored for both zones through social learning and knowledge coproduction with multiple stakeholder participation. Also, general education on the impact of climate and extreme weather events and various strategies for adaptation based on both traditional and scientific knowledge sources for capacity building.

The rapid erosion of the relevance of traditional signs and symbols (Sumi, 2018) for weather prediction due to climate impacts necessitates that farmers look for alternative information sources for decision-making. As revealed by study findings, most farmers use weather forecast information by listening to radio or television, accessing daily weather forecasts on rainfall and temperature for planning their farm activities. However, for the sustainability of smallholding farming, more specific, detailed, and tailored climate information is required for decision-making (Vaughan et al., 2018; Agyekum et al., 2022).

Additionally, farmers should have other information such as new farming techniques, market trends, new crop types, pesticides and impact of climate on crop yields alongside their traditional knowledge in decision-making. This is important to feed into farmers' choices and farming decisions such as changing in dietary requirement by cultivating crops that may provide better performance.

The study revealed that, in the Guinea savanna zone, cassava cultivation is fast replacing yam production as cassava is recorded to have a high tolerance to poorer weather conditions such as longer drought and poorer soil. Also, maize cultivation has replaced sorghum production, as such the focus group discussant asserted that their children did not know 'tuo zaaf' (traditional dish) prepared using sorghum previously but current using maize.

But Stuch et al. (2021) revealed that tropical cereals (sorghum and millet) have a higher temperature tolerance than maize, making tropical cereal more suitable in the study zones than maize production. Also, Traore et al. (2017) reported from Mali that maize grain yield loss of up to 57 % caused by climate change could be offset by applying recommended fertilizer doses. Similar conclusions were drawn for pearl millet, but with a lesser effect of climate change on this drought-resilient crop (10 % loss in grain yields). Undoubtedly, farmers' access to this type of information will ensure choices that maximise the advantages in producing crops that will give the most produce. However, in the absence of such information, farmers seem to have been making choices that may have negative impact, since heat stress is predicted to considerably reduce yields in cereals (Traore et al., 2017).

While farmers access information from various sources including family and friends, radio remains the preferred medium for weather information in the study area. In the Guinea savanna zone, this preference is largely due to local radio stations broadcasting in the local dialects, making the information more accessible to most of the smallholder farmers with low level or on education. In contrast, the respondents in the Sudan savanna zone preferred television, which is mostly broadcast in English, possibly reflecting their higher levels of formal education.

The findings show that the delivery of weather information must reflect the preference of the farmers. This implies that policymakers need to develop systems for delivering weather information tailored to farmers' needs, easily accessible and useful for decision-making and planning. Depending on the region or community, weather information could be delivered through agriculture extension services, mobile apps, SMS, or radio. Choosing an appropriate medium is important to the delivery of weather information, as it determines whether recipients can access and use the relevant information at the required time. However, no matter what service is employed, it must be easily accessible and affordable to the end users. For instance, a proportion (22.6 %) of farmers stated that they do not use weather forecasts because they do not own mobile phones or radio sets to listen to the forecasts.

This augurs well for coproduction of knowledge using both TK and SK in policy formulation on the forms of weather information and medium to use for delivery in each sub-district for effective utilization by local communities. Also, since credible weather information is key if farmers will access the information, the farmers' involvement in policy formulations on the type of information and delivery could build trust in the use of the information for decision-making. This will cater to the portion of farmers who stated that they do not use climate information due to the unreliability of the information provided. Since farmers will have both climate and other information based on their experience and scientific decision-making, they will have complementary information that ensures appropriate decisions that they can trust.

3.4.5 Farmers' training and group activities

Although some of the smallholder farmers have seen some benefits of training, their experience can be described as limited since the follow-up training to ensure that the skills were acquired, or that modern technologies or techniques were adhered to did not take place. Occasional training and a two-year wait for the next training schedule, as indicated by the focus group discussions, does not put farmers at an advantage after climate variation. Smallholder farmers need more information and interaction with specialists to combat the effects of climate change on farming activities.

If extension services are to be used as a channel for weather information delivery, then there is the need to overhaul the system to enable delivery of tailored services that farmers can use to adapt and build resilience for the sustainability of farmer households. As shown by findings from the focus group discussions, though few farmers participated in farm group activities, there is no doubt that many benefits could be derived from them. If this potential is harnessed, agriculture extension delivery could take on a different dimension for cost effective services.

3.5 Conclusions

This chapter revealed that smallholder farmers' perceptions of the changing environment influence their decision-making in coping and adaptation choices on and off-farm.

Perceived changes in temperature and rainfall patterns due to climate change were exhibited by smallholder farmers in the study. The changes observed have negatively affected food production, leading to the suggestion of gradual deepening of poverty and hunger among smallholder farmers. Although farmers adopt traditional techniques to adapt to the changing weather, the study concludes that it is evident that more needs to be done by combining them with modern technologies for adaptation which could help support resilience building of farming systems and livelihood.

Farmers are changing the types of crops cultivated due to the decrease in yield that they attribute to changing climate based on their perception. Evidence in the literature shows that some of the crops being dropped can do well under the scenarios of high temperature, decrease in rainfall, and changing rainfall patterns. Therefore, local research on the effects of climate on the yields of traditional crops, such as sorghum, millet, and rice are required to ensure that the farmer's decision to shift from traditional crops to introduced crops is based on accurate information.

The chapter also reveals that smallholder farmers primarily receive general weather forecast, daily temperature and rainfall updates through radio and television. However, this information is often too broad to effectively support decision-making in the context of a rapidly changing climate. Farmers require detailed and tailored climate information, coupled with advice on possible adaptation practices that can complement their traditional techniques based on understanding of their local environment. But the absence of this information and the lack of education on climate change and its impacts on crop production has left farmers in a somehow perplexed state, as nothing they do seems to produce the expected results, the study has shown.

The chapter further revealed that farmers prefer public extension service delivery since they find it beneficial. However, the time available for farmer engagement is so minimal that farmers seem in limbo when it comes to climate changes. And with the extension staff to farmer ratio of 1 to 1300 farmers (Anang et al., 2020), even if all the extension workers are deployed, the minimum of a two-year gap, as revealed by the study, between engaging farmers will not suffice in the wake of climate variability. Also, there is the need for an overhaul of the information delivered to meet the specific needs of farmers based on their preferences. Furthermore, there are still a fraction of farmers who do not trust weather forecasts enough to depend on them or use them alongside their own predictions.

The chapter concludes that meteorologists, extension agents, and farmers need to work together to design weather and agricultural information and advisories that are suitable for smallholder farmers to improve uptake and utilisation. As agricultural extension agents play a central role in any agricultural extension system, and with the quality of the system dependent on their effectiveness, it is necessary to enhance the capacity of the agents to provide the most appropriate services.

Chapter 4

Traditional knowledge and climate change adaptation by smallholder farmers in two agro-ecological zones in northern Ghana

Objective 3: To determine the various adaptation strategies used by farmers.

Objective 4: To outline the traditional knowledge used and how it augments the use of scientific methods in adaptation to climate variabilities.

Research question 2: What strategies are farmers employing that are informed by traditional knowledge to adapt to these climate variations?
Research question 3: Which combined strategies have become a regular practice used by farmers?

Hypothesis: The chapter hypothesised that factors that will influence the development of strategies to manage climate change variation will include the agro-ecology zone, gender, age, position in household, land ownership type, land area, number of plots available, level of education, access to weather information, farming years, perception/observation in climate variation, and agricultural training received. These factors are based on findings of previous authors that traditional coping strategies by smallholder farmers to climate variabilities are altered by many socio-economic and environmental factors (Deressa et al., 2011; Ndamani & Watanabe, 2016; Osei 2017; Antwi et al., 2018; Yamba et al., 2019).

Abstract

Smallholder farmers in Ghana have been adjusting their farming practices to adapt to changes in natural climatic conditions to sustain their livelihoods. However, never has there been such a fast pace of change in natural weather as seen with current anthropogenic climate change variabilities. The impact of these variabilities on farming activities of smallholder farmers as predicted in literature is threatening to deepen hunger and food insecurity in developing nations where smallholder farming systems depend mostly on rain-fed agriculture. Smallholder farmers are adapting by using their traditional knowledge to combat these variabilities in the fast-changing environments in anticipation of enhancing resilience in the

farming system and their livelihoods. This chapter, therefore, aimed to examine the various adaptation/coping mechanisms of smallholder farmers in facing climate variations and to explore how traditional techniques are employed alongside scientific technologies.

The study covered four districts from two agro-ecological zones in northern Ghana, using a logistic regression model to determine the factors that informed farmers' choices in adopting both traditional and scientific technologies combating climate change impact locally. The study employed mixed methods, using both quantitative and qualitative methodologies, such as questionnaires, focus group discussions, and in-depth interviews with smallholder farmers, elders, and opinion leaders in the selected communities.

The study’s findings show that the farmers' perception or observed changes in weather, household head, available crop techniques, and access to weather information positively influence farmers' decisions. However, education level, number of plots, gender, agro-ecological zone, number of crops grown and number of years in farming had a negative impact on decision-making. The farmers use mixed cropping, various crop techniques (early-maturing, disease, pest, and drought-resistant varieties), and shifting cultivation for crop management practices. Mulching, mound-making, and bunding are employed for water conservation practices though due to choices in land clearing methods, bunding and mound-making is gradually becoming obsolete due to its unsuitable manual construction. Findings also show that farmers are becoming more prone to debt, due to an increase in input costs with declining yields.

Furthermore, traditional knowledge seems to be losing its appeal in the communities due to a lack of awareness of the full benefits of some techniques practiced. In addition to the rapid rate at which climate impact wipes out practices based on nature, making them less effective. Even so, since farmers will continue to use traditional knowledge due to its low or zero cost, it could be used as a basis for targeted agro-ecological education on climate change adaptation.

4.1 Introduction

African smallholder farmers' knowledge and management decisions are mostly informal, but they are becoming recognised for being exceptionally well-informed, making their contribution to local and regional adaptation planning significant (Morton & Abendroth, 2017; Šūmane et al., 2018). Their choices are also rooted in information essential to socio-cultural complexity such as geography, language, resource usage practices, religion, and belief systems (Tengö et al., 2014) and are classified as indigenous, local, or traditional knowledge.

This knowledge is believed to be the accumulation of time-tested experiences in which they adapt to local situations to handle environmental, social, administrative, and health issues, including resource utilisation and community integration (Radeny et al., 2019). The use of traditional techniques is embedded in their experience and knowledge in adjusting and adopting practices to adapt to climate change impacts in their communities for the sustainability of their livelihoods.

These practices include adjustable daily farm activities and long-term initiatives according to Leal Filho et al. (2021), which they expect can lead to farm system resilience and sustainability in the wake of climate impacts. Traditional knowledge is thus acknowledged for its potential to play a critical role in climate change adaptation (IPCC, 2021; 2022), resource governance, conservation, and the sustainable use of biodiversity and ecosystems (IPBES, 2018). Also, with the potential to contribute to the achievement of the Sustainable Development Goals (Tengö et al., 2014).

4.1.1 Traditional Knowledge

Traditional knowledge (TK) is the wisdom, innovation, and practice of native and local communities around the world. The knowledge is formed from exposure earned over the years through experimentation (Gadgil et al., 1993). Teran (2018) defined traditional knowledge as an oral collection of knowledge that has been extended through generations over the years in adaptable and active communal establishments with socio-economic and ecological beliefs, worldviews, and political processes. Traditional knowledge is ingrained in the close relationship of local societies with nature and ecosystems due to the bio-cultural nature of their practices and the belief that all living beings are connected as part of nature (Teran, 2018). Therefore, traditional knowledge is experiences acquired over a period that is tailored to local customs and settings and is transferred verbally generationally (CBD, 2016).

Furthermore, according to the UNESCO (2017), local and indigenous knowledge comprises the considerations, techniques and values created by societies after years of mingling with nature. Thus, the land is the essential foundation of intelligence, wisdom, and ethnic differences between communities (Teran, 2018). However, the definition of traditional knowledge depends on the ethnic, environmental, and rightful settings of its usage. This has led to numerous definitions, as noted, though there is no globally accepted definition due to the complexity of the knowledge gained and its usage.

In distinguishing between the three mostly used names – Indigenous knowledge is 'body of knowledge held by Indigenous people or local knowledge unique to a given society '(Berkes, 2017: 7). While local knowledge is said to be knowledge acquired by any group living off the land in a particular area over a long period of time (Langill, 1999). These according to some practitioners bound the knowledge to locality, thus exempting non-indigenes that have lived in the locality for a long time. Traditional knowledge then is a cumulative body of knowledge, practice, and belief, evolved by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment (Berkes, 2012) whereas Indigenous knowledge is defined to be a body of knowledge built up by a group of people through generations of living in close contact with nature (Johnson, 1992). However, indigenous people are said to be origins of an area or geographical location with their own culture and belief system distinct from the international systems of knowledge.

4.1.2 Description of traditional knowledge

Traditional knowledge is described as dynamic, all-inclusive, and transmitted from one generation to another through connected experiences in native dwellings. The moral value of this knowledge depends on sustaining the credibility of the land itself (Battiste, 2005). In literature, there have been several terms used to describe traditional knowledge. For example, indigenous knowledge (Gadgil, Berkes & Folke, 1993), local and traditional knowledge (Thornton & Maciejewski, 2012), local ancestral knowledge and practices, traditional ecological/environmental knowledge (Berkes, Colding & Folke, 2000; Díaz et al., 2015; Berkes, 2018). Also, traditional wisdom (Turner et al., 2000) and indigenous and local knowledge systems (Díaz et al., 2015), indigenous technical and rural knowledge as well as ethno-science or people's science (Altieri, 1995). Traditional knowledge is sometimes described as verbal customs in song, dance, painting, sculpture, chants, and performances through the centuries. However, its realistic nature appears in farming, fisheries, health, horticulture, forestry, and conservation management in general (CBD, 2016).

In support of this, the World Intellectual Property Organisation (2018) pointed out that traditional knowledge comprises the content of knowledge itself, coupled with traditional cultural languages, including distinguishing emblems and symbols. Hence, traditional knowledge is jointly expressed in songs, myths, stories, ethical principles, proverbs, public regulations, rituals, local dialects, and agricultural practices, and relates to the advancement of improved plant and animal species (WIPO, 2018).

4.1.3 Features of traditional knowledge

According to Delanty (2000), traditional knowledge as a worldview consists of cultural values combined with practices and knowledge systems linked to metaphysical, ecological, and technological fields. Indigenous knowledge consists of a unified body of knowledge that includes:

a. Learning systems: traditional ways of counting and quantifying, indigenous games, processes of invention, and explorations of approaches to information dissemination.
b. Control measures: traditional regulations, taboos, rituals, environmental management, decision-making processes, conflict resolution and common property practices.
c. Culture: expressed in songs, values, stories, beliefs, secret societies, local languages, dances, and proverbs.
e. Medicine: covers a wide range of practices – herb treatment, disease classification, medicinal plant use and storage methods and classification of local flora and fauna. Traditional healers divided into herbalists, spiritualists, and ritualists with varying training and qualifications.
f. Agriculture: knowledge of seasons for planting/harvesting, land preparation, propagation of plants, seed storage, and methods of using manure as fertilizer.
f. Traditional knowledge of textiles, local crafts, building materials, indigenous tools, and energy conservation (Kargbo, 2006).

4.1.4 Values of traditional knowledge

Traditional knowledge holds immense value through communities' deep-rooted understanding of their surroundings, serving as a strength of immeasurable worth. The natural diversity of the landscape, essential to all living beings, is preserved in local dialects, rituals, and customs, offering insights into nature comparable to those housed in the libraries of modern science (Nkomwa et al., 2014; Jiri et al., 2016; Makate, 2019). Moreover, the importance of local knowledge extends beyond familiarity with soils, plants, and animals; it plays a critical role in climate change mitigation and adaptation strategies (Smith & Sharp, 2012; Makondo & Thomas, 2018). Examples include the use of environmental indicators for climate monitoring (Speranza et al., 2010; Ndamani & Watanabe, 2016; Ansah & Siaw, 2017), composting plant residues to improve soil fertility (Radcliffe, Parissi & Raman, 2016) and classifying soils to optimise crop production and yields (Osbahr & Allan, 2003). Additional practices involve using leguminous plants in mixed cropping and agroforestry for nitrogen fixation, relying on native plants for food security during dry seasons, and applying natural methods for soil and pest management (Radcliffe et al., 2018)

Indigenous knowledge techniques are typically low-cost, rely on local resources, and often align with the ritual and cultural practices of societies (Gorjestani, 2000; Lodhi & Mikuleckey, 2010). They also contribute to the sustainability of farming practices, enhance food security, and strengthen food system resilience under climate change (Lwoga, Ngulube & Stilwell, 2010; Mbow et al., 2019). According to WIPO (2018), this knowledge emerges from rational actions and practiced skills within an established system. For rural communities, however, it is deeply embedded in daily decision-making, shaped by complex cultural elements such as language, classification systems, social relations, resource use, rituals, and spirituality (UNESCO, 2017).

In terms of social learning, a diverse knowledge base can serve as a foundation for communal learning by bringing together individuals with different expertise to share their knowledge, experiences, and perspectives, thereby enhancing community capacity (Ensor & Harvey, 2015; Thi Hong Phoung et al., 2017). Through cooperation, societal actors can develop alternative viewpoints that strengthen the community's ability to withstand shocks (Bos et al., 2013). For example, Choudhury et al. (2021) described Indigenous and Local Knowledge (ILK) as a form of social learning, noting that it originates within social groups and communities of practice. ILK is built through empirical observation and trial-and-error processes, transmitted across generations, and deeply rooted in local institutions and traditions (Berkes, 2018; Trogrlić et al., 2019). Additionally, traditional learning–by–doing and doing–by–learning is embedded in social learning cultivated through process of experimentation that is essential to overcome stable and difficult to change socio-technical system or introduction of technologies in the community (Brugge & Rotmans, 2007).

4.1.5 Traditional Knowledge and Science Knowledge

According to Arce and Long (1992), knowledge determines how people comprehend the world surrounding them. Munyaradzi (2014) asserted that knowledge in general terms could be understood as an individual belief that is justified in some ways with the ability to influence one's thinking, actions, and behaviour. In the concept of knowledge co-production, knowledge is regularly construed as something out there (an implement, a framework, devising or resolution to an issue, etc.) that leaders could use in future development.

Knowledge can therefore be expressed, combined, and disseminated through scientific articles, knowledge appraisals, and books that can be comprehended orally or by reading. Hence, it is global and not bound to the lifestyle of a particular place or people (Mahony & Hulme, 2016; Balvanera et al., 2017; Beier et al., 2017).

Conversely, Lodhi and Mikulecky (2010), purported that knowledge is generated and spread through social interactions between perceptible and imperceptible and can follow four basic patterns:

- People share intangible knowledge through personal contact.
- Substantiation of the intangible by turning it into tangible form to benefit others through codification of the experiences, judgments and insights.
- Tangible to tangible (mixture) pattern, where individuals synthesise knowledge to create a new whole.
- Tangible to intangible (incorporation) pattern, in which individuals use the codified knowledge of others to broaden their own intangible knowledge.

According to Parsons et al. (2017), the Indigenous knowledge system has different but interconnected dimensions: governance and management practices, cosmology that encompasses ethics and values, and data that includes observations of places, processes, and relationships. However, complex and insecure natural and social worlds require the resolution of existing problems using diverse types of knowledge (Conklin, 2001).

Moreover, since knowledge is not uniform, varied knowledge can provide the public with diverse viewpoints to contextualise issues (Wang, 2015). But to Berkes and Berkes (2009), indigenous and scientific knowledge have both comparable and non-comparable attributes. However, scientific, and indigenous knowledge are both vital avenues for the public to view the world and shape matching remedies. Also, indigenous, and scientific knowledge have clearly distinctive characteristics; the former is traditional, verbal-based, qualitative, oral, indicative, and local, while the latter is recent, number-based, documentary, quantifiable, exact, and worldwide (Berkes & Berkes, 2009).

In support, Moller et al. (2004) listed the complementarity of both knowledges in five respects, as presented in Table 4.1.

Table 4.1: Complementarity of science and traditional knowledge (Moller et al. 2004).

Science	Traditional Knowledge (TK)
Science is synchronic (short time sequences) and tends to collect short-term data over large areas.	TK is diachronic (long time sequences) and collects information over long periods.
Science focuses on averages.	TK focuses on the extremes.
Science deals with quantitative information.	TK is qualitative information.
Science utilises approved tests of mechanisms.	TK utilises improved hypotheses.
Science is objective.	TK is subjective.

Science and traditional knowledge (TK) can complement each other in data collection: science provides broad, synchronized data over large areas in short periods, while TK offers long-term, place-based insights that serve as valuable baselines. Because weather events span both time and space, integrating these knowledge systems leads to more comprehensive decision-making. As Folke et al. (1998) noted, TK offers temporal depth but may be event-specific, whereas science can detect changes across regions and explain their underlying causes.

While much of science is based on collecting numerical data, with emphasis on statistical analysis of averages, holders of traditional knowledge are exceptionally good at observing extreme events, variations, and unusual patterns and remembering them through oral history and social memory.

Science emphasizes quantitative data from specific parts of a system, while traditional knowledge provides a qualitative, holistic understanding. Since complex systems require both detailed measurement and broad context, the two approaches are complementary. Qualitative methods are typically faster and more affordable but less precise. In low-resource settings where traditional harvests are common and scientific research is costly, simple, rapid, and reliable monitoring methods are crucial (Moller et al., 2004).

Traditional knowledge helps generate relevant hypotheses, while science explains the underlying "why." Though science may explore less relevant questions, combining both offers context and analytical depth. Chalmers and Fabricius (2007) showed that local insights revealed observed changes, while science explained broader patterns and predicted unseen trends.

Science seeks objectivity by excluding people and emotions, while traditional knowledge embraces them, strengthening community ties. Scientific methods often distance researchers from nature, whereas traditional knowledge stays grounded in local context (Nakashima & Roué, 2002).

Observation is key to both traditional and scientific knowledge (Berkes & Berkes, 2009). Traditional knowledge develops through long-term, community-based observation, while science often relies on short-term studies by external researchers (Sutherland et al., 2014). Unlike the bottom-up nature of traditional knowledge, science is typically top-down and institutionally supported, enjoying higher status and more advanced systems (Sen, 2005; Sillitoe & Marzano, 2009).

Scientific knowledge is seen as more economically efficient, while traditional knowledge lacks the structure and innovation to boost productivity and income. However, climate change impacts have shown that science alone is incapable to address complex environmental and social issues, making traditional knowledge vital for effective policy design (Raymond et al., 2010; Cullen-Unsworth et al., 2012; Byg & Salick, 2009; Weber, 2010).

Scientific knowledge enables expertise and evaluation of actions for long-term effectiveness. However, climate adaptation programs rooted in Western science often marginalize indigenous knowledge, treating it as less valuable (Whitfield et al., 2015; Belfer et al., 2017; Lesperance, 2017).

Since knowledge systems often influence each other (Makondo & Thomas, 2018), integrating scientific and traditional knowledge through a multiple evidence-based approach can enhance climate adaptation. This fosters social learning, embeds shared understanding in communities, and builds social memory, key to resilience and effective responses to future shocks (Berkes, 2007; Folke et al., 2005; Reed et al., 2016).

4.1.6 Summary

Traditional Knowledge (TK) is widely recognized internationally as a valuable resource, developed over generations through close interaction with the environment. It is deeply embedded in cultural practices, technologies, socio-economic beliefs, worldviews, and political processes, and is typically passed down orally (CBD, 2016; Teran, 2018).

Historically, TK has played a significant role in both ecological and farming systems, and more recently, in climate change mitigation and adaptation (Smith & Sharp, 2012; Makondo & Thomas, 2018). Techniques derived from TK, such as environmental indicators for climate monitoring, soil improvement practices, and local soil classification systems, have been proven effective in enhancing crop yields and supporting sustainable agriculture (Osbahr & Allan, 2003; Ndamani & Watanabe, 2016; Radcliffe, Parissi & Raman, 2016; Ansah & Siaw, 2017). These methods are cost-effective, utilize locally available resources, and are tailored to specific local environments. As a result, TK holds significant potential to enhance sustainable agriculture, ensure food security, and strengthen food system resilience in the face of climate change (Mbow et al., 2019).

Despite these advantages, TK has often been marginalized due to its non-scientific methods of accumulation, which are viewed as lacking empirical rigor (Whitfield et al., 2015; Belfer et al., 2017; Lesperance, 2017). However, with the growing urgency of human-induced climate change, TK is gaining renewed attention especially as effective climate adaptation increasingly requires location-specific strategies. This has highlighted the importance of co-producing knowledge from multiple sources to inform climate policy and action with the key challenge lying in harmonizing these distinct knowledge systems within policy frameworks as TK used by local communities is rarely documented (Patt & Gwata, 2002; Vogel & O'Brien, 2006).

Although there has been significant global progress in documenting TK, many African countries lag in both the preservation and systematic recording of traditional knowledge. TK in Africa remains at risk of extinction due to globalization and its continued reliance on oral transmission (Maluleka & Ngoepe, 2018; Ogar et al., 2020; Owolabi et al., 2022; Mdhluli et al., 2021). Scholars such as Okorafor (2010), Adeniyi and Subair (2013), and Madar (2024) noted that African Indigenous Knowledge is often poorly managed with its oral nature leading to distortion or loss when knowledge holders pass away.

Like many African nations, Ghana faces a pressing need to close the documentation gap by building a comprehensive repository for TK and establishing institutional frameworks to protect intellectual property rights. This is essential for ensuring the incorporation of TK into policy frameworks for the benefit of society. This chapter contributes to this effort by profiling and documenting the climate adaptation technologies used by smallholder farmers, drawing on both traditional and scientific knowledge systems.

4.2 Materials and methods

4.2.1 General characteristics of the study zone

The study was conducted in two agro-ecological zones (Sudan and Guinea savanna) of northern Ghana that are characterised as vulnerable to climate change variations due to weather conditions (refer to section 2.3).

4.2.2 Methods

The study used mixed method models for the collection of data (refer to section 2.5).

4.2.3 Data analysis

The data was collected using an offline survey software from Lighthouse Studio 9.12.1, exported to Microsoft Excel 2010 for cleaning. (refer to section 2.6).

4.3 Results

4.3.1 Land preparation management strategy

4.3.1.1 Land preparation

Climate variations in terms of changing rainfall patterns such as delay in onset of rains and shorten rainfall demand that farmers adopt ways to prepare their land to meet rains for cultivation to ensure productivity within a farming season. For instance, with shortened rainfall within a season, land preparation must be done promptly at the right time for sowing to ensure water for plant growth. Thus, traditional ways that community members support each other at different times within regular predicted time of the start of the rains for the season could no longer hold, requiring farmers to adapt using a quicker way to do so.

Overall, 65.5% of the farmers indicated that they have changed their land clearing methods due to changing climatic conditions for the past ten years. Of these respondents who have changed their general land clearing techniques, 74.7 % indicated the use of either tractor or animal-driven ploughs while 23.3 % still slash-and-burn (traditionally method of clearing of land for cultivation) to prepare their land. 13.6 % of farmers use mound-making (specifically for yam production) compared to 9.5 % that used zero-tillage, while 22.6 % farmers indicated the use of other methods not listed (Figure 4.1). Thus, the use of tractor- or animal-driven ploughs and zero-tillage have now replaced slash-and burn (manual clearing of farmland using cutlass and hoes after which the weeded vegetation is gathered and burnt before sowing) for land preparation. Mound-making is also gradually phasing out in the communities since cassava cultivation does not require mounds.

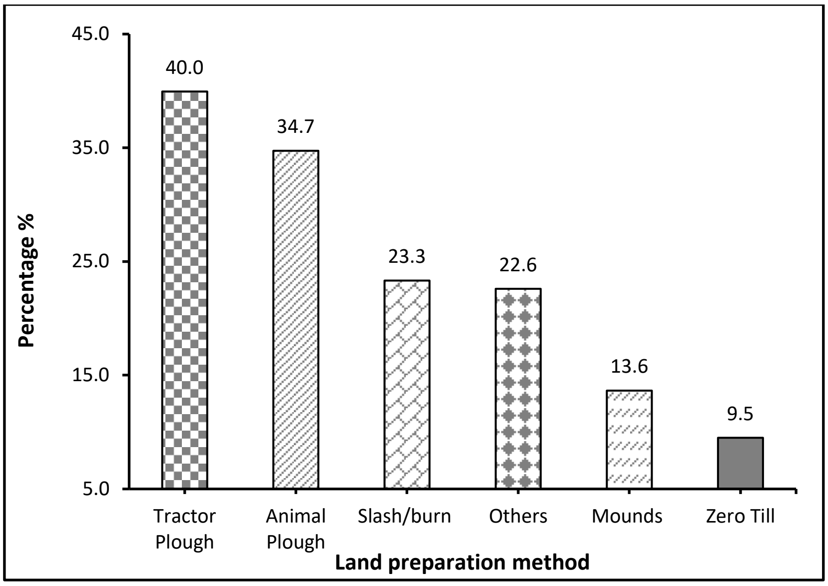


Figure 4.1: Preferred new land preparation methods used by smallholder farmers in two agro-ecological zones in northern Ghana.

However, the results showed a difference in the use of animal-driven ploughs between the two agro-ecological zones {Kruskal–Willis's test: $X^2 = 159$ (df=1, N_1=140, N_2= 142) respectively, p <.005} while the use of zero-tillage, slash and burn, tractor-driven ploughs, and mound-making were not statistically different between the zones. This indicates that farmers apply the techniques equally between the zones as deemed appropriate.

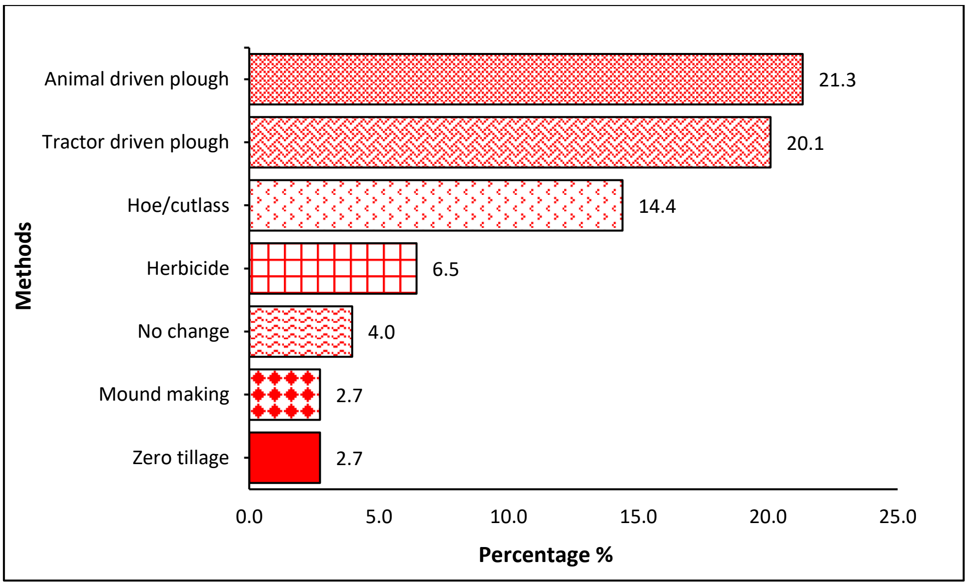


Figure 4.2: Methods regularly used for land preparation by smallholder farmers in two agro-ecological zones in northern Ghana.

The results showed that a section of farmers (41.4 %) preferred the use of either animal or tractor-driven ploughs (Figure 4.2). Farmers further explained that it is faster and less laborious to use the driven implement in land clearing. This is supported by Fonteh's (2010) finding that a farmer with manual tools prepares about 0.5 hectares in a season at an average of 93 hours compared to 10 hours with draft animals and only a few hours with a tractor (Houssou et al. 2013). In support of this, Josiah, Bani, and Mahama (2008) and Taiwo and Kumi (2015) asserted that tractors are the most visible mechanised technology for smallholder farming in Ghana after the Green Revolution in 2006.

Most of the farmers also used combined techniques for preparing their land according to the soil type and condition coupled with the crop type. For instance, combinations listed in the open-ended question included the use of animal plough with burning; slash-and-burn with herbicides, hoe/cutlass with herbicides, or zero-tillage with herbicides. Farmers resourcefully used the knowledge of their environment to their advantage in preparing their land. The rest of the farmers mentioned hoe/cutlass, herbicides, mound-making, and zero-tillage as their regular land preparation methods, combining techniques when necessary. However, 4.0% said that they have not changed the way they prepare their lands, without further indicating what techniques they have been using.

The farmers explained that their choices were based on their tested method, ease of access, and affordability of the inputs used. No matter what the preferred technique, the farmers mentioned that they either own the equipment or have easy access to it to use, while stating the disadvantages of not using the other techniques. According to 14.4 % who use hoe and cutlass, they explained that tractors or animal ploughs are too expensive for them, while hoeing is affordable and time-tested.

4.3.2 Soil management techniques

4.3.2.1 Farmers 'preference in fertilizer used

In the wake of the reduction in soil fertility due to climate variations (Darge et al. 2018; Anang et al. 2021), most respondents indicated using both organic and inorganic fertilizers to improve soil fertility, although organic manure application has been their traditional method. The results (Figure 4.3) show that the respondents, despite the combined use of organic and inorganic fertilizers, prefer the organic fertilizers in the form of compost, mulch, plant residues and animal droppings, which is consistent with Aniah et al.'s (2019) findings that smallholder farmers are using appropriate agronomic practices, including manuring, composting, organic manure application, crop residue management and animal droppings, which they supplement using inorganic fertilizer as an adaptive practice to combat soil fertility depletion.

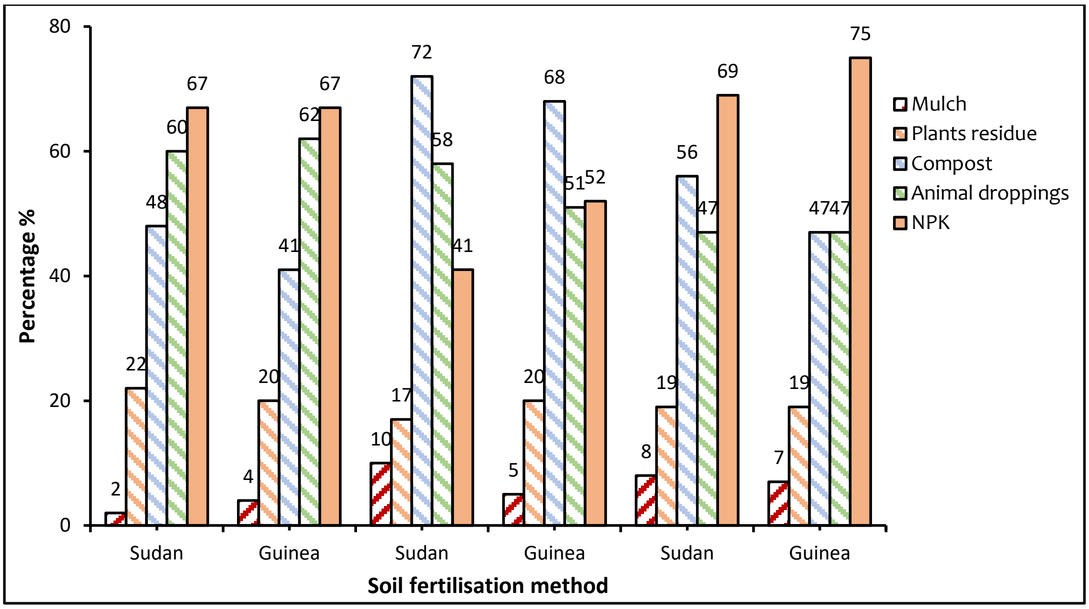


Figure 4.3: Smallholder farmers' selection of preferred soil fertilisation method using the best and worst preference scale and using five attributes (mulch, plants residue, compost, animal droppings and NPK) in three choices per farmer from two agro-ecological zones in northern Ghana

4.3.2.2 Soil water conservation techniques

Soil water conservation strategies have become essential as climate variations, such as extended droughts, shorter rainfall periods, and intense rainfall that fails to penetrate the soil, have led to a gradual decline in soil water availability for plants. Farmers must adapt to these changes to ensure sufficient soil moisture for crop growth. Respondents adopted different strategies such as mulching, mound-making, terraces, ridges, and irrigation to ensure the availability of water for their crops as shown in figure 4.4, consistent with reports from Melka et al. (2015) and Recha et al. (2016). Conversely, 44.7% indicated that no adoption of techniques were applied. A Kruskal Wallis test gave a statistical significance difference in irrigation (X^2 = 76.24, df= 1, p=0.001); creation of ridges (X^2 = 24.76, df= 1, p= 0.001); creation of terraces (X^2 = 8.48, df= 1, p= 0.004); and none of the above (X^2 = 23.12, df= 1, p=0.001), while there is no statistical significance difference for practising mulching ($X^2 = 2.30$, df=1, p= 0.129) and making of mounds ($X^2 = 0.35$, df=1, 0.553) across the two agro-ecological zones.

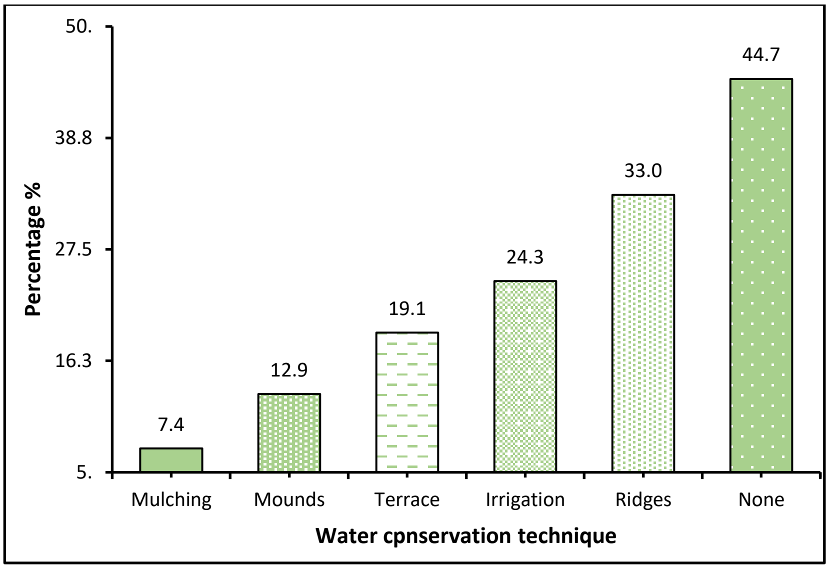


Figure 4.4: Soil water conservation techniques employed by smallholder farmers in two agro-ecological zones in northern Ghana.

A cross-tabulation of the adapted practices (Table 4.2) revealed that 86 respondents from the Sudan savanna zone practice irrigation, compared to just 11 from the Guinea savanna zone. This difference may be due to the proximity of the Tano Dam in Navrongo, which provides easier access to irrigation water for those in the Sudan savanna zone (GSS, 2014). Additionally, 90 respondents from the Sudan savanna zone reported using ridges to conserve soil water, while 43 respondents from the Guinea savanna zone employed this method. Conversely, 50 respondents from the Guinea savanna zone practiced terracing, compared to 27 from the Sudan savanna zone.

Table 4.2: Description of water conservation techniques adopted by smallholder farmers in the two agro-ecological zones in northern Ghana

		Water conservation techniques					
		Irrigation	Mulching	Ridges	Mounds	Terrace	None
Agroecological zone	Sudan	86	19	90	28	27	66
	Guinea	11	11	43	24	50	114
Total		97	30	133	52	77	180

The Guinea savanna zone recorded the highest number (114) of respondents reporting non-adaptation compared to 66 from the Sudan savanna zone. The findings showed that farmers in each of the zones adopted technologies that were easily accessible, practical, and suited to their farming practice. This is consistent with findings from Hassan and Nhemachena (2008), Seo et al. (2009), Deressa et al. (2011) and Bate et al. (2019), that climate change adaptation is more effective when it is locally based and requires the use of a locally specified strategy.

Focus group discussants confirmed using methods like raised beds, ridging, mound-making, earthing-up, and bunding for water conservation during planting (Figure 4.5). In the Sudan savanna zone, discussants reported using bunds around rice farms to retain water and prevent runoff, while in the Guinea savanna zone, mounds are raised for yam cultivation.

Irrigation in the Sudan savanna zone is practiced along irrigation channels for rice cultivation, away from homes. In the Guinea savanna zone, farmers irrigate fields near rivers using river water when needed. However, crops like millet, cassava, and maize rely solely on rainfall and are typically grown flat with minimal tilling, apart from clearing weeds and retaining plant residue as mulch.

Figure 4.5: Farmland prepared using bunds, Sudan agro-ecological zone, northern Ghana

Discussants noted a decrease in crop residue, which they attributed to the hybrid varieties being developed to reduce water loss through the stomata on their leaves. Unlike local varieties, these hybrids leave fewer vegetative parts after harvest, resulting in less mulch material (Figure 4.5 a&b). Additionally, mulching and composting practices have declined, with compost pits no longer being dug during the off-season, as they were a decade ago.

In the Nania community of the Sudan savanna zone, discussants reported that mulching materials and organic matter have become scarce, partly due to climate change. They explained that improved crop varieties produce fewer vegetative parts than local varieties, and the limited mulch available is often consumed by free-range livestock, leaving little for farming use.

Figure 4.6a: Harvested plot with crop residue in Chiana Nyegeya in the Sudan agro-ecological zone

Figure 4.6b: Harvested plot with crop residue in Chiana Nyegeya in the Sudan agro-ecological zone

Earthing-up was also mentioned as a technique used around crops to ensure that high rainfall intensity and wind speed do not uproot the plants. When asked what other purpose the earthing-up serves, the discussants did not know that it can serve as a cooling system around the roots of the plant and that it conserves water for plant use. When asked to describe how a stick pushed deeper into an earthed-up system looked, they had an 'a-ha 'moment when they recognised the moisture normally found on the stick, prompting a discussant from Sudan savanna FGD to comment: "*No wonder our fathers were so serious about earthing up during the dry period in the planting seasons."*

From the respondents, all techniques used are mostly in harmony with nature ensuring that less harm is caused to the environment as much as possible since traditional values enshrine that humans are part of nature. These old techniques used by the farmers are traditional methods that have been employed for ages to adjust to changing climate from time memorial incrementally expected to lead to enhancing adaptive capacity of the system with time.

4.3.2.3 Years of practice of techniques

Most of the respondents (78 %) indicated that they have been practising techniques to adapt to climate change for over five years while 22 % have been using the techniques for less than five years (Figure 4.7). In assessing the effectiveness of their chosen methods to conserve water for crop production, the respondents gave varying responses. A total of 114 of them replied affirmatively, mentioning that practices such as irrigation had enabled them to farm throughout the year. For instance, in the Sudan savanna zone, dry season vegetable cultivation is done due to access to irrigation facilities (GSS, 2014). Other respondents mentioned methods such as mulching, terracing, and ridging to prevent the run-off of surface water, reduce water loss through evaporation, and prevent topsoil erosion either by water or wind. Some farmers also believed that the construction of irrigation facilities will support their farming activities during the dry season, which concurs with previous studies that indicate that access to farm input aids adaptation to climate change (Deressa et al., 2009; Armah et al., 2013).

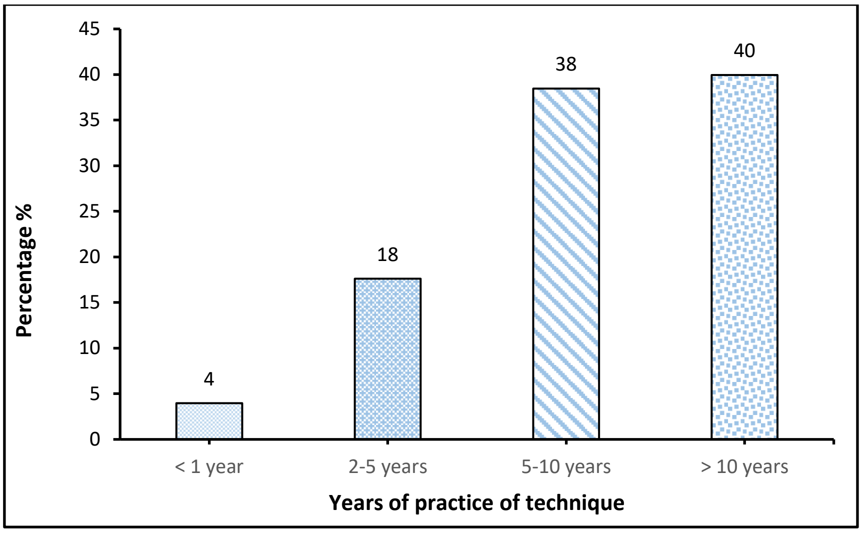


Figure 4.7: Number of years smallholder farmers have been using techniques in their farms in two agro-ecological zones in northern Ghana.

The farmers that responded negatively (56 %) explained that they do not use any of the methods on their farms and are dependent on rainwater alone. Some also stated that the water ran quickly off the farm to other lands. This is interesting as it may be due to applying the wrong coping mechanism on the farm. This supports the assertion by Gyampoh et al. (2009) that rural people used various coping strategies to adapt to climate change with mixed success. It also confirms the conclusion by Addaney et al. (2021) that it is important to identify appropriate climate change adaptation management practices that will reduce crop risks with multiple on-farm and landscape benefits. Furthermore, as the soil is only covered with crop plants, water collected quickly moves away to other areas with little percolation.

4.3.3 Crop management strategies/techniques

To adapt to climate change variation in the local environment, previous findings indicated that smallholder farmers use various agronomic practices such as changing the planting date, planting early-maturing, drought-disease-and pest-resistant varieties, changing the type of crops grown, changing land preparation methods, and using crop diversification as well as using scientific or traditional weather forecasts (Belay et al., 2017; Antwi-Agyei et al., 2021).
Farmers mentioned changes in crop type, planting date, the use of new seeds, the use of new, drought-resistant, and early maturing varieties and others, as mentioned in previous studies by Adjei-Nsiah and Kermah (2012) and Marie et al. (2020).

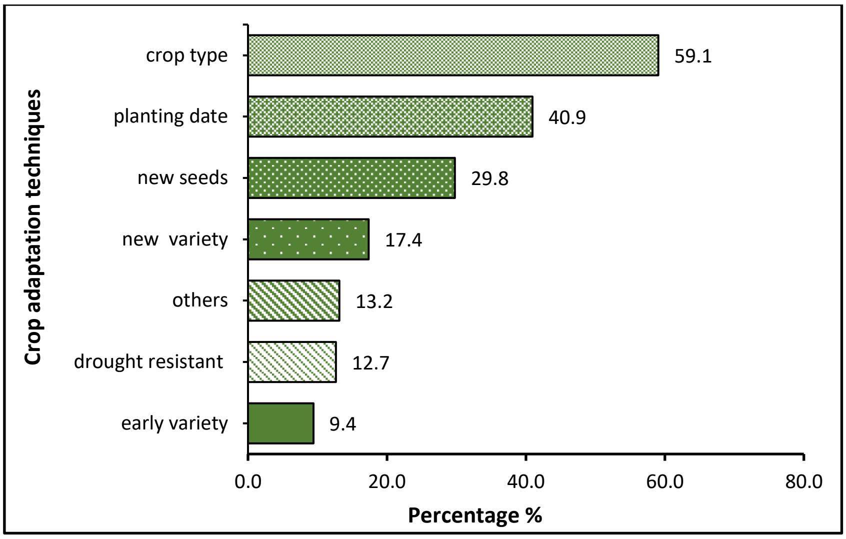


Figure 4.8: Description of crop adaptation techniques used by smallholder farmers in two agro-ecological zones in northern Ghana

The most practiced adaptation techniques are change of crop type (59.1 %) and change in planting date (40.9 %), supported by Tun Oo et al. (2017), Marie et al. (2020), Devi et al. (2020) and Antwi-Agyei et al. (2021) while the least used technique is the early-maturing varieties (9.4 %) (Figure 4.8). Farmers used other techniques (13.2 %; Figure 4.8) that were considered in more detail in the FGDs. The focus group discussants also confirmed the adoption of improved hybrid varieties such as early maturing varieties instead of traditional varieties to offset the shortened rainfall pattern. For instance, maize is harvested within two-and-a-half to three months, which is within the current rainfall duration due to climate changes.

The discussants also highlighted delayed sowing as a strategy to adapt to changing conditions. By adjusting the start of the season and waiting for the onset of rain, farmers ensure sufficient water for seed germination, seedling survival, flowering, and fruiting. This approach is particularly important in maize production, as a lack of water during flowering and grain filling can reduce yields drastically (Sah et al., 2020).

The farmers' adoption of disease-resistant varieties (X^2 = 2.52, df= 1; p-value= 0.11), new seed (X^2 = 0.76, df= 1; p-value= 0.38) and new crop varieties (X^2 =, 0.88; df= 1; p-value= 0.35) were not statistically different across the zones using Chi square tests. However, the change in crop types (X^2= 8.08, df= 1; p-value =0.004), the use of drought-resistant varieties (X^2= 34.16, df= 1; p-value =0.001), early-maturing varieties (X^2 = 7.44, df= 1; p-value =0.006), the change in planting date (X^2= 4.12, df= 1; p-value =0.042) and other techniques (X^2= 11.50; df= 1; p-value=0.001) were statistically significant different across the zones.

As shown in Table 4.3, the number of farmers (1,445)[2] from the Guinea savanna agro-ecological zone that adapted using crop management techniques was slightly higher than the number of farmers (409) from the Sudan savanna agro-ecological zone. Farmers in the Guinea savanna zone recorded greater adoption preference in six techniques, compared to greater adoption of two different techniques by farmers from the Sudan savanna zone. There is a notable difference in the use of drought-resistant varieties by farmers in the two zones (Table 4.3).

Table 4.3: The number of smallholder farmers indicating their preferred crop-based technologies in two agro-ecological zones in northern Ghana.

Techniques/Technologies	**Agroecological Zones**		Total
	Sudan Savanna	**Guinea Savanna**	
Use of disease-resistant varieties	49	36	85
Use of new seed	56	64	120
Use of new crop varieties	31	38	69
Change in crop type	133	105	238
Use of drought-resistant varieties	**6**	**45**	**51**
Use of early-maturing varieties	11	27	38
Change in planting date	72	92	164
Other techniques	15	38	53
Uncompleted	36	0	36
Total count	409	445	854

Given that the Sudan savanna zone experiences slightly higher daily mean maximum temperatures (38°C to 42°C) and a longer dry period (5 months) without rainfall, compared to the Guinea savanna's daily mean maximum temperature range of 36°C to 38°C and 4-month-long dry spells with intermittent rainfall (GSS, 2014), we would expect a higher adoption of drought-resistant varieties in the Sudan savanna zone.

With easy access to irrigation facilities within the Sudan savanna zone, more farmers used irrigation instead of soil water conservation methods (Table 4.3), which influenced their choice of cropping technique. Thus, farmers choose other technologies such as early maturing and disease-resistant varieties. Similarly, respondents from the Guinea savanna zone adopted drought-resistant varieties, even with long rainfall patterns in terms of duration and amount

[2] Totals from multiply choice answers made by participants

per season. But when there is poor access to irrigation facilities, farmers choose techniques that ensure resilience within the cropping system. This supports the conclusions of Owusu and Yiridomoh (2021) in Ghana and Dendir and Simane (2019) in Ethiopia that agro-ecological zone location contributes significantly to smallholder farmers' sensitivity to climate change variation and hence calls for context-specific strategies to increase the smallholder farming system's capacity for adaptation.

4.3.3.1 Changing crop types

Agricultural and livelihood diversification are strategies used by African households to cope with climate change enabling them to spread risks and adjust to shifting climate conditions (Thierfelder et al., 2017; Thornton et al., 2018). The results showed varying reasons for the adoption of particular techniques such as shortened rainfall, late onset of rains, and longer drought periods, leading to changes in cropping systems. This was consistent with findings by Adjei-Nsiah and Kermah (2012), who indicated that farmers are shifting from cocoa to maize-based cropping systems in the cocoa-growing regions in Ghana due to climate change variations. Farmers (59.1 %) also indicated a change in diet because of changes in the cropping system. Others (13.2 %) also stated that adoptions were made to ensure an increase in yields that would allow them to have some economic benefits after feeding their families and to manage soil nutrients by growing different crops with complementary nutrient requirements.

In confirmation, the focus group discussants indicated that changing crop types were used to adapt to the varying climate conditions (shortened rainfall period) in their localities. For instance, maize and cassava have been introduced in addition to traditional crops like millet, guinea corn, sorghum, and yam. According to the discussants, maize performed well and has gradually replaced the production of other cereal crops as it yields better and has an available market. As expressed by a female key informant in Sudan savanna zone: "*Maize yields much more and has higher demands than millet.*" The farmers' assertion of reduction in yields of traditional crops such as millet and sorghum are supported by literature that showed that increased in temperature under climate change will after crop yields (IPCC, 2014). Cassava, for instance, is projected as viable option to replace many crops in Africa due to its hardiness to higher temperatures and sporadic rainfall pattern experienced by the farmers (Jarvis et al., 2012; IPCC, 2014).

Crops like guinea corn (in the Guinea savanna zone) and early millet (in the Sudan savanna zone) have been phased out of cropping systems for about a decade due to their low yield performance. This decline is attributed to shortened rainfall seasons, delayed onset of rains, and the lack of improved varieties that can withstand changing climatic and extreme weather conditions. However, access to modern technologies is believed to strengthen farming households' adaptive capacity, potentially enhancing the resilience of agricultural systems for socio-economic growth (Mtega et al., 2016; Danso-Abbeam et al., 2018; IPCC, 2021). Thus, the discussants, on observing the impact of changes in their environment, experimented and adopted practices to ensure sustainability of their livelihoods.

Table 4.4: Previous and current cropping systems in descending order showing the previous crops that have been dropped from the cropping system due to the impact of climate change in two agro-ecological zones in northern Ghana

Zone	Cropping system
Guinea Savanna	**Previous cropping system in descending order –** early millet, late millet, guinea corn, yam, bambara bean, groundnut, maize, cassava. **Current cropping system in descending order–** maize, cassava, early millet, late millet, yam, bambara bean, groundnut, (**Guinea corn dropped due to shortened rainfall pattern**).
Sudan Savanna	**Previous cropping system in descending order** – early millet, late millet, rice, sorghum, guinea corn, bambara bean, groundnut, soyabean, maize. **Current cropping system in descending order** – maize, rice, late millet, sorghum, guinea corn, bambara beans, groundnut, soyabean. (**Early millet dropped due to delay in onset of the rains**).

Furthermore, the production of crops that are not performing well under a changing climate are reduced as a means of adaptation consistent with Antwi-Agyei et al., (2014) and Altieri et al., (2015) findings of adjusting crop choices. Because of these changes in the cropping systems, families have changed their dietary requirements to adapt to the changes made in the cropping system (Table 4.4). For instance, they explained that they have changed to maize and rice-based diets but use mostly maize for preparation of 'tuo zafi,' a traditional meal in both zones that used to be made from millet and guinea corn. This was asserted by a female discussant from Sudan savanna FGD: "Our children do not know millet-based 'tuo zafi', they grew up with maize-based 'tuo zafi' and will not eat one made from millet."

The poor performance of the crops was due to changing climate conditions resulting in low yields. This was consistent with literature that stated that smallholder households have changed their dietary requirements due to the impact of climate change to ensure food security (Shisanya & Mafongoya, 2016; Oliver, 2016; Kangmennaang et al., 2017; Kerr et al., 2019). Harvested millet, for instance, is mostly processed into a local drink (pito) or porridge for sale to add to the family income since the yields are not sufficient for the family to depend on while the production of guinea corn is for ritual purposes when needed. As indicated below from all the FDGs interactions: *"Millet, guinea corn and sorghum are cultivated now for ritual purposes when needed and for preparing porridge or pito [local non-alcoholic beverage] for sale to supplement family income since yields are not sufficient for families to depend on."*

Through the substitution of crops in the farming system as an adaptive measure to climate and extreme weather variabilities, farmers are taken advantage of commercial value of crops such as cassava, rice, and maize resulting from the unintended consequence of shocks in transforming the cropping system as adaptive capacity. In addition to the building of resilience to future climate shocks and sustainability of productivity, that has the potential to lead to livelihood transformation from subsistence farming to market-oriented production with market availability produces as testified by farmers.

However, depending on the system used (mono-cropping or mixed cropping) could exposed farmers to other risks such as further degrading of soil, increase use of inorganic fertilizers for especially maize and rice cultivation (additional cost component to production). These may negate the gains in yields that can lead to maladaptation as indicated by Griscom et al. (2017) that non-native monoculture plantation is 'maladaptive' in ecosystem services.

4.3.3.2 Number of crops grown per season

The results revealed that 92.1 % of farmers cultivate two or more crops per season with the highest number being four crops and the least two while 7.9 % of farmers planted only one crop (Figure 4.9). This is consistent with the finding by Osei (2017) that crop diversification (multiple cropping) is the most dominant adaptation method by smallholder farmers in three agro-ecological zones in Ghana.

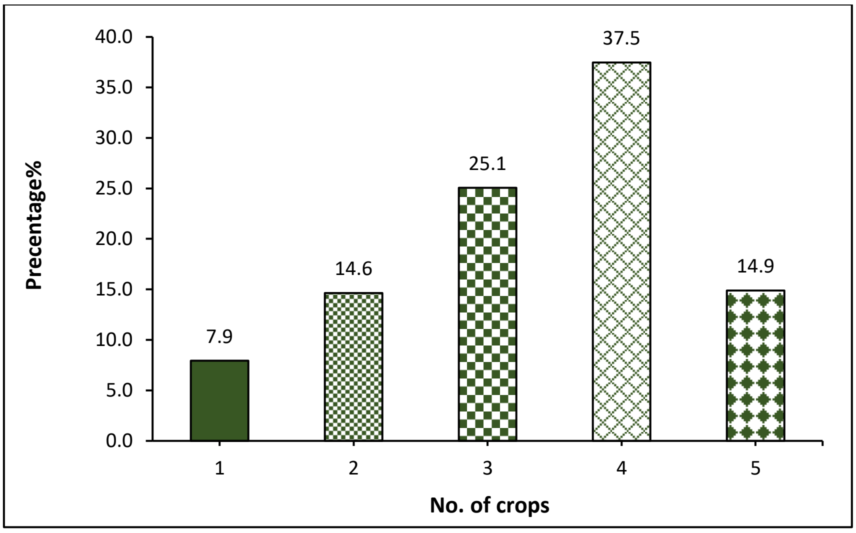


Figure 4.9: Number of crops grown per season by smallholder farmers in two agro-ecological zones in northern Ghana.

Farmers also used one or more strategies such as mono-cropping, mixed cropping, cropping rotation and shifting cultivation within a cropping season (Callo-Concha, 2012) alongside the cultivation of multiple crops. Mixed cropping was the most practiced method, used by 41.2 % of farmers, supporting assertions that most farmers in Ghana engage in intercropping to minimise the risk of crop failure from drought or flooding (Asante & Amuakwa–Mensah, 2015) followed by 39.5 % respondents using mono-cropping, and 5.7 % respondents practising crop rotation. Few farmers (3.5 %) indicated using both mono and mixed cropping and fewer still (2.0 %) employed shifting cultivation.

Furthermore, farmers explained that using mono-cropping depends mostly on the type of crop and stating that a crop like rice cannot be mixed with others on the same plot due to the flooded paddy field that other crops cannot tolerate. Conversely, farmers who practiced mixed cropping had two or more crops on the same plot, either interspersed with crops such as maize, millet, groundnut, guinea corn, sorghum, yam, and rice (FAO, 2011; Callo-Concha, 2012) or are planted on different parts of the field. Contrary to Hassan and Nhemachena (2008)'s findings that mono-cropping is most susceptible to climate change impacts, respondents who practice it indicated that it ensured good yields. Also, the farmers explained that their choice of practices was based on these factors: changes in rainfall patterns, full use of land, food security, proper farm management, good yields, availability of land, crop type and traditional practice(s).

4.3.4 Experience in use of technique/technology

Years of experience (practice) is often cited in the literature as a determinant influencing climate change adaptation choice (Deressa et al., 2009; Gbetibouo, 2009; Armah et al., 2013). Most respondents (78.4 %) indicated that they have been practising their choice of technique(s) for more than five years, while the remaining (21.6 %) have practiced the technique for less than five years. However, when asked how they acquired the skills applied, most farmers (86.8%) stated that it was the traditional practice passed down by their elders, combined with their own experiences gained on the farm (Figure 4.10).

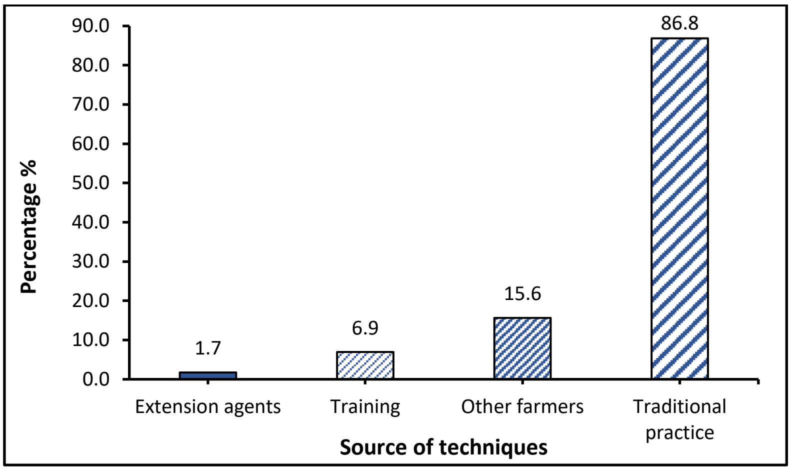


Figure 4.10: Sources from which smallholder farmers acquire the farming techniques being used in two agro-ecological zones in northern Ghana

Also, 15.6 % of the farmers said that they learned from other farmers while 6.9 % indicated that the knowledge was obtained from training and 1.7 % stated it came from agriculture extension officers. A correlation analysis (r = 0.188, 0.185, 0.256; N= 371; p=0.001, 0.003, 0.011; two-tailed) revealed a significant positive correlation between those who learnt from training and the few farmers (25.1 %) who indicated they had received agricultural training within the past five years, through contact with either extension agents or non-governmental organisations. As indicated by a male discussant from the Guinea savanna FGD: *"I do not remember the last time I saw an Agric officer in my community."* Likewise, literature findings showed that due to the 1:3500 agriculture extension officer to farmer ratio (Swanson & Rajalahti, 2010), that required the stepping in of agricultural NGOs to bridge the gap in provision of essential services for sustainability of smallholder farming livelihood (Buadi et al., 2013).

Most (48 %) of the farmers mentioned that practising the techniques has given them food security and variety in their dietary provisions consistent with findings in the literature (Shisanya & Mafongoya, 2016; Oliver, 2016; Kangmennaang et al., 2017; Kerr et al., 2019).

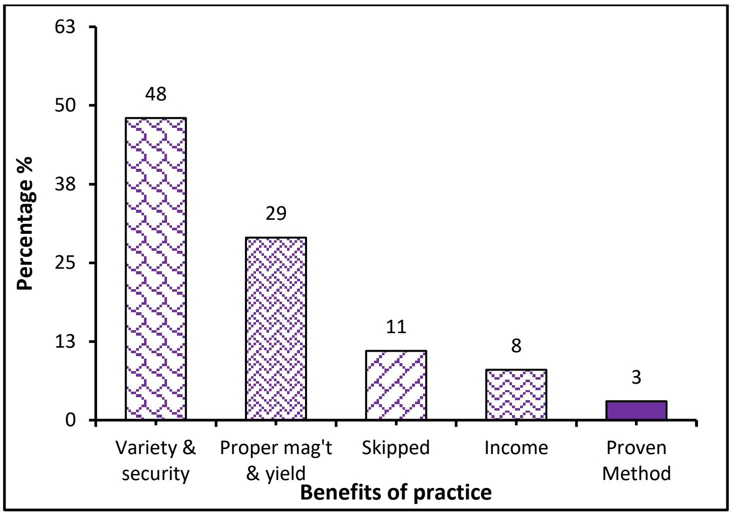


Figure 4.11: Description of benefits gained by smallholder farmers from farming practices used in two agro-ecological zones in northern in Ghana

A further 29% of the farmers mentioned that their choice of technique(s) has helped to ensure management of their farms. Choices such as efficient fertilizer use, pest control regimes and maximisation of land area utilised, these have translated into an increase in yields, while 11 % skipped the question. The remaining 8 % indicated that the practice was adopted to increase yields for sale as a source of income for the household since excess produce is sold in subsistence farming. Lastly, 3 % mentioned that the techniques used were handed over to them traditionally as a proven method (Figure 4.11).

4.3.5 Plots available for farming

Numerous studies have shown that smallholder farmers adapt to climate change by adopting fallowing technique (where plots are allowed to lay bare without cultivation over a period) (Mabe et al., 2014; Uddin et al., 2014) and by diversifying their crops requiring accessibility to more land. The results revealed that most farmers (91.1 %) have access to two or more plots, while 8.9 % indicated that they had only one plot available for cultivation (Figure 4.12), coupled with a size ranging from less than one to four hectares and larger (Figure 4.13). This, according to Mabe et al. (2014), gives smallholder farmers an advantage as having access to multiple small plots makes it easier to adopt fallow practices through shifting cultivation, an option that is often less feasible for farmers managing larger farm sizes.

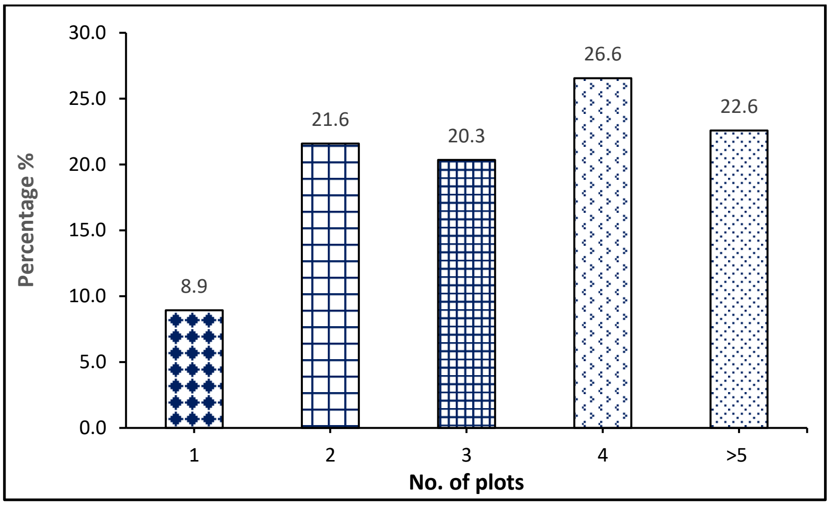


Figure 4.12: Description of number of plots available to smallholder farmers for utilisation in two agro-ecological zones of northern Ghana

However, recent IPCC (2020) projections of doubling of population on the Africa continent may put pressure on land use leading to loss of farmland to urbanization (Thornton et al., 2018). With the reduction in number of plots, traditional practices such as fallowing period for soil replenishment will either be completely or shortened exacerbating the depletion of already poor nutrient soils and its inherent reduction in productivity of farming system.

4.3.6 Land size available for farming

When asked about the ownership of the cultivated land, 69.2 % of farmers indicated that it was self-owned, 33.3 % family-owned, on lease (8.9 %), or on a shared lease (1.7 %). There was a significant difference between genders for the self-owned type ($U = 16036$, $N= 403$; $p=0.014$; two tailed) and shared lease ownership type ($U= 17693$; $N= 403$; $p= 0.06$; two tailed) using Mann–Whitney test, while family land ownership ($U= 17124$, $N= 403$; $p=0.23$; two tailed) and leased ownership types ($U= 18173$; $N= 403$; $p=0.93$; two tailed) were not statistically significant. Some farmers (38.4 %) indicated that they are maintaining their current farm size, followed by 34.0 % who have reduced their farm size, while the remaining 27.8 % have increased their farm size in the last ten years (Figure 4.13).

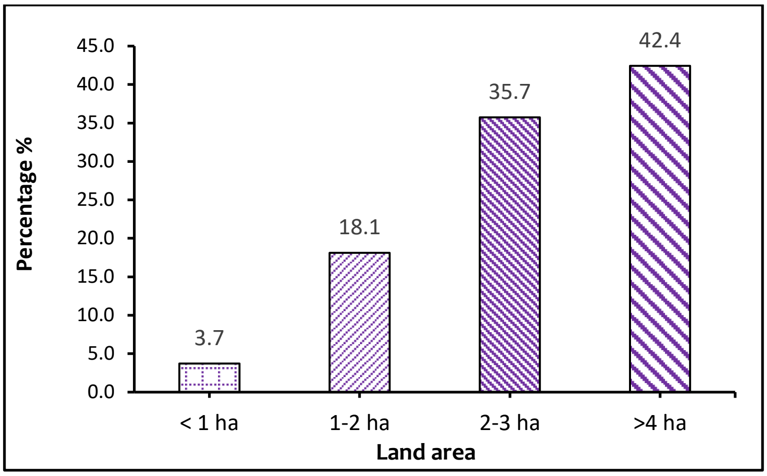


Figure 4.13: Description of land area available to smallholder farmers for utilisation in two agro-ecological zones of northern Ghana

4.3.7 Changing farm size

Uddin et al. (2014), Mutunga et al. (2018) and Buckland and Campbell (2021) reported the change of farm size as one of the factors used by farmers as an adaptive strategy for climate change adaptation. Farmers changed their farm size under three categories (Fig 4.14) with varying reasons feeding into the decision-making process.

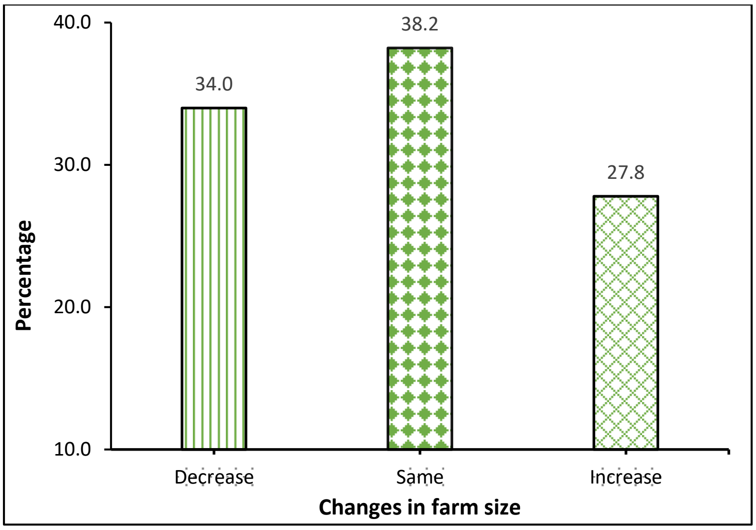


Figure 4.14: Changes in farm size over a ten-year period undertaken by smallholder farmers in two agro-ecological zones of northern Ghana

Of the 34.0 % farmers that reported decreasing their farm size, 18.1 % responded to change in rainfall pattern resulting in insufficient water for crop growth consistent with IPCC (2014) report of irregular rainfall pattern in certain regions due to climate variations. Also, 7.9 % mentioned weakened labour strength due to aging, poor availability, and lack of affordable farm inputs consistent with Armah et al. (2013)'s finding that lack of inputs influences farming decisions on adoption of technologies. Furthermore, 6.8 % of land was fallowed to replenish the soil naturally to adapt to soil depletion due to climate impact (Mabe et al., 2014). Yet, 1.2 % lost their farmland to other activities, such as the construction of buildings and the sale of land by other family members consistent with reports from FAO (2022) and IPCC (2022) that increasing population in SSA will put pressure on land uses.

A section of the farmers (13.6 %) increased their farm size due to an increase in family size that meant availability of additional labour while 12.4 % increased their farm size to increase their yield. Very few farmers (1.8%) increased their farm size due to increased access to inputs (Figure 4.14).

4.3.8 Empirical Model for Logistic regression models

A binary logistic regression model was used for this study based on the hypothesis that farmers strategies are influenced by socio-economic and environmental factors. Farmers either developed strategies using their experiences and local knowledge to cope with climate variabilities and extreme in combination with scientific knowledge, or they do not.

The logistic regression model is an appropriate statistical tool to determine the influence of independent variables on dependent variables when the dependent and explanatory variables have only two groups or categories (dichotomous) and/or are categorical in nature. The logistic models sought to identify the magnitude and direction of the factors influencing the choices for adopting adaptation strategies based on traditional knowledge or otherwise by smallholder farmers in the two agro-ecological zones. Therefore, the likelihood of a certain farmer adopting adaptation strategies to adapt to climate change can be described by a logistic model. This study considered two sets of adaptation strategies: those related to the adoption of changes in land management practices and those related to changes to crop management practices. Therefore, the study analysed each of the adaptation sets independently and separately.

Table 4.5: Description of independent variables used in the study to examine smallholder farmer adaptations to changing climatic patterns in two agro-ecological zones in northern Ghana

Explanatory Variables	Mean	SD	Description of Variables
Observed/perceived weather change	0.97	0.18	dummy, take the value 1 if yes and 0 if otherwise
Years of practice of technique	3.14	0.85	Continuous
Number of crops grown	3.37	1.14	Continuous
Ways to predict weather traditionally	0.45	0.50	dummy, take the value 1 if yes and 0 if otherwise
Weather forecast preference	0.87	0.82	dummy, take the value 1 if yes and 0 if otherwise
Agriculture training received within past 5 years	0.25	0.43	dummy, take the value 1 if yes and 0 if otherwise
Number of plots available to respondent	3.32	1.28	Continuous
Land size available to respondent	3.17	0.85	Continuous
Gender	0.34	0.47	dummy, take the value 1 if male and 0 if otherwise
Position of respondent in household	0.33	0.47	dummy, take the value 1 if head and 0 if otherwise
Agroecological zone	0.50	0.50	dummy, take the value 1 if first category and 0 if otherwise
Sum water conservation methods	1.41	0.75	Summation of variables categories; Continuous
Sum crop methods	2.04	1.10	Summation of variables categories; Continuous
Sum land ownership types	1.13	0.35	Summation of variables categories; Continuous
Level of education	0.50	0.50	dummy, take the value 1 if above primary level and 0 if otherwise
Farming years	0.85	0.36	dummy, take the value 1 if 10 years and above and 0 if otherwise
Age of respondent	0.56	0.50	dummy, take the value 1 if 45 year and above and 0 if otherwise
			N: 403

Table 4.6: A Logistic Regression Model showing factors influencing the decisions of smallholder farmers on land management-related adaptation in two agro-ecological zones of northern Ghana

Variables	Exp (B)	Probability	95% CI	P-value
Observed/perceived weather change	4.45	0.82	1.26–15.71	0.020**
Years of practice of technique	0.69	0.41	0.51–0.93	0.014**
Ways to predict weather	2.13	0.68	1.25–3.61	0.005***
Land ownership type	1.24	0.55	0.58–2.62	0.580
No. of crops grown seasonally	0.67	0.40	0.51–0.87	0.004***
Number of plots	0.68	0.41	0.51–0.91	0.009***
Land size available	2.17	0.69	1.44–3.28	0.001***
Water conservation techniques	1.02	0.51	0.74–1.40	0.91
Crop techniques	1.51	0.60	1.17–1.94	0.002***
Farming years	0.62	0.38	0.29–1.31	0.210
Gender	0.60	0.38	0.36–1.01	0.054*
Constant	3.59			0.00***

N = 403

Nagelkerke R Square = 0.30
Chi-square = 10.96
Significance level= 0.20
2 Log likelihood = -417.6
Overall correct prediction = 73.3%

*** p<0.01, ** p<0.05, * p<0.1

The parameters of land ownership type, water conservation techniques, and farming years were not significant, while the observed/perceived weather change and years of practice of techniques were significant, at the 5 % level, in determining land preparation adaptation methods. The ways of predicting weather, number of crops grown seasonally, number of plots for respondents, land area available for respondents, and sum of crop techniques were significant at 1 %. Also, gender was significant at the 10 % level. Of the eight significant variables, four were positive, namely, the observed/perceived weather change, ways to predict weather, land size available for respondents, and sum of crop techniques. The remaining four variables of years of practice of techniques, number of crops grown seasonally, number of plots for respondents, and gender had negative coefficients.

Table 4.7: A Logistic Regression Model showing factors influencing the decisions of smallholder farmers on crop management-related adaptation in two agro-ecological zones of northern Ghana

Variables	Exp (B)	Probability	95% CI	P-value
Number of crops grown seasonally	0.71	0.42	0.52–0.97	0.029**
Weather forecast preference	1.94	0.66	1.07–3.51	0.029**
Number of plots	0.28	0.22	0.20–0.40	<0.001***
Land size available	2.99	0.75	1.81–4.93	<0.001***
Water conservation techniques	0.36	0.27	0.25–0.58	<0.001***
Crop techniques	2.04	0.67	1.51–2.76	<0.001***
Gender	0.29	0.23	0.14–0.64	0.002***
Agro-ecological zone	0.24	0.19	0.13–0.45	<0.001***
Position in household	3.15	0.76	1.14–7.12	0.024**
Age	1.06	0.51	0.57–1.90	0.89
Level of education achieved	0.49	0.33	0.26–0.93	0.030**
Constant	124.24			0.000***

N = 403

Nagelkerke R Square = 0.56
Chi-square = 11.36
Significance level= 0.182
2 Log likelihood = -328.1
Overall correct prediction = 82.3 %

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

The parameter for the age of respondents is not significant while the number of crops grown, weather preference, position of respondent in household and level of education achieved were significant at the 5 % level. The number of plots, land area available, water conservation techniques, crop techniques, gender, and agro-ecological zone were significant at the 1 % level.

However, it should be emphasised in both models that an Exp (B) value of less than one indicates a negative parameter constant which implies that high values of the variable tend to decrease the probability of choice of adaptation by farmers to climate change variabilities. In contrast, an Exp (B) greater than one indicates a positive parameter constant, implying that high values of the variables will increase the probability of farmers' choices for adaptation using land or crop management technologies, keeping all other variables constant.

The analyses of statistically significant explanatory variables and the findings from this study that are consistent with other findings are discussed.

4.3.8.1 Logistic regression models result

The model's result indicates that farmers have an 81.7 % probability of adopting climate change adaptation strategies using land management techniques when they observed/perceived climate variations and extreme weather events. This is consistent with findings by Tun Oo et al. (2017) that farmers are influenced by their perception of climate variations and specific issues surrounding farming systems. Access to weather information, whether scientifically or traditionally, had a positive impact on the choices of adaptation strategies, with probabilities between 66.0 % and 68.0 %. This result aligned with Saguye (2016) in Ethiopia, Ndamani and Watanabe (2016) in Ghana, and Mutunga et al. (2018) from Kenya, with findings of a positive relationship with access to weather information and the adoption of strategies to adapt to climate variations.

The models revealed that the land area available to farmers has a positive probable effect, between 68.5 % and 74.9 %, on the farmers’ choices in adaptation to changing weather conditions. This aligns with Belay et al. (2017), who found that farmers often expand their farm size by integrating crop and livestock production and cultivating various fodder trees when they have access to larger areas of farmland.

Thus, farmers with large farmland areas can practice using water conservation practices, land management techniques like fallowing, multiple cropping and mixed cropping to adapt to climate change locally. In contrast, Mabe et al. (2014) noted that access to several plots, coupled with small size, is advantageous for smallholder farmers to facilitate the adoption of fallow system and shifting cultivation, unlike farmers with large farmlands.

Additionally, the models showed a 60.1 % and 67.1 % probability of farmers positively adopting technologies in both land preparation– and crop management – related adaptations. Considering the soil type, weather predictions, and indigenous practices such as cover cropping and mulching, can help reduce surface erosion. Also, strategies such as crop diversification, mono-cropping, multi-cropping, disease- and drought-resistant varieties, and early maturing varieties in crop management adaptation are consistent with findings by Belay et al. (2017) in Ethiopia and Antwi-Agyei et al. (2021) in Ghana.

Furthermore, the models revealed a positive probable effect of 72.2 % for the adoption of climate change adaptation measures if the decision-making for crop management adaptation is done by the household head rather than a member of the household. This means household heads are predisposed to adopt for climate variations consistent with findings from Ndiritu et al. (2014) in Kenya of female headed household adopting sustainable agricultural methods.

The model results revealed negative effects with a 29.1 % probability for farmers adaptive choices regarding water conservation strategies for crop management adaptation. Farmers are therefore prone to adopt water conservation methods for land preparation, rather than in crop management adaptation. This implies that the farmer will choose irrigation or a technique that will conserve water rather than choosing drought-resistant crops when the two options are presented in a decision and planning session within a season.

Furthermore, the results showed that the number of years that farmers had been practising techniques had a significant negative effect on the farmers' decision to adopt new techniques for land preparation with a 40.7 % probability. The number of crops grown had a negative effect on the farmers' decision on adoptive choices using land and crop management, with a probability between 39.9 % and 42.1 %.

Gender is significant with a probability between 26.4 % and 37.5 %. Thus, male farmers are less likely than females to adapt to climate change using land and crop management practices. This may be due to female farmers often cultivating marginal lands near their homes, which typically have lower soil fertility, requiring them to adopt various coping and adaptation strategies to secure food for household consumption. Agyo and Oman (2018) found that female-headed households are more likely to diversify income-generating activities as a climate change adaptation strategy. While men typically engage in farming, women are more involved in processing and off-farm activities such as trade.

The number of plots available to farmers had a negative and significant influence, with a probable influence between 20.8 % and 40.6 % for farmer choices on adaptation. This is inconsistent with findings by Mabe et al. (2014)'s, who advocated that numerous plots are advantageous to farmers 'adaptive decisions, as they can practice traditional agronomic practices such as fallowing and shifting cultivation.

The model's results showed a negative relationship between formal education and the adoption of traditional agronomic practices, with a 32.6% probability. This aligns with findings by Okoye (1998) and Gould et al. (1989), which also noted that formal education negatively correlates with adaptation decisions. Since traditional practices are often passed down orally and require little formal education, farmers with higher education levels represented by 15.4% of respondents are more likely to adopt scientific methods instead.

The models' result indicated a limited influence of agro-ecological zone on farmers' adaptive choices accounting for only 19.3 % of variations in decisions. While Deressa et al. (2009), suggest that farmers in different agro-ecological zones tend to adopt distinct adaptation strategies. This study found farmers' decisions were more strongly influenced by the availability of inputs from their agro-ecological context.

4.4 Discussion

Smallholder farming households in developing world have been reported of using agricultural and livelihood diversifications as strategies for adapting/coping with climate change (Thierfelder et al., 2017; Thornton et al., 2018). These included shifting planting date, changing crop types, land size, location of farms, adopting hybrid crop varieties (Antwi-Agyei et al., 2014; Altieri et al., 2015; Bawakyillenuo et al., 2016).

4.4.1 Determinants of climate decisions and actions by smallholder farmers

The logistic models revealed information regarding the smallholder farmers 'choice of farming management activities to adapt to climate change using their traditional knowledge and experience. Evidence from the models showed that the farmer's choices are influenced positively by factors such as observation or perception of weather changes, weather information, area of land available, and crop techniques for adopting expertise that will ensure plant growth and yields despite the changing climate.

The model's findings showed that the area of land available to farmers had a high influence on adaptive choices in management techniques for land preparation, water conservation, and crop management. The study revealed that farmers in both agro-ecological zones are either decreasing, maintaining, or increasing their farm area as an adaptive strategy, consistent with conclusions by Mutunga et al. (2018) and Buckland and Campbell (2021) that farmers change farm size as a strategy for climate change adaptation.

However, findings in the literature on land area as an adaptation measure have been conflicting. For instance, several findings (Blarel et al., 1992; Mabe et al., 2014; Veljanoska et al., 2018; Gilli et al., 2020; Ndip et al., 2023) have shown that small plots are advantageous to farmers for practising shifting cultivation, crop diversification and fallowing as adaptive techniques. Also, small plots in different locations allow farmers to exploit the uniqueness of various micro-environment for different crops growth resulting in risk management coupled with food and nutritional security of farming households (Cholo et al., 2019; Ndip et al., 2023; Mayele et al., 2024). Vijayasarthi and Ashok (2015) on the other hand showed that farmers with small farm sizes adapt to using technologies that require labour intensive management since the farming area do not support mechanisation.

In contrast, Abdollahzadeh et al. (2012), Latruffe and Piet (2014) and Sklenicka et al. (2014) reported increase in production cost, prevention of timely performance of operations such as irrigation, transplanting and pest control. Additionally, dispersed small plots restrict farmers' use of modern technology and increase travel time between plots thereby undermining efficiency of land use that result in decreasing productivity and livelihoods. Larger farm areas were also found to enable farmers to practice adaptive measures, such as agri-silviculture and crop diversification, in combating climate variations (Madison 2006; Tesfaye & Seiful, 2016; Belay et al., 2017). Lu et al. (2018) on the other hand concluded that moderate farm size had become the trend in agriculture due to the rising cost and non-agricultural labour supply necessitating for farmers to decrease their plot size.

Likewise, the farmers' decisions on land usage are varied depending on the circumstances. For instance, farmers cultivate smaller areas with fewer crops to ensure sufficient soil water to support plant growth, thus adapting to the effect of shortened rainfall patterns. However, the availability of more than one plot to farmers had a negative probability of adoption of techniques for adaptation to climate change. This requires policy interventions that would ensure that farmers are utilising the best options to maximise productivity amidst climate and weather variabilities. For instance, Velijanoska (2018) advised policymakers to be cautious in implementing uniform land consolidation programs from findings that showed that loss of crop yield decreases with rainfall variations on highly fragmented plots. Although, crop performance on high fragmentation plots remained unfavourable for farming households not experiencing rainfall irregularities.

While land ownership has been reported as a barrier for smallholder productivity, especially for female farmers in sub-Saharan Africa, this study's findings showed that most farmers owned the lands they cultivate on or are farming on family (clan) land, allowing them to adopt farming practices without issues stemming from land ownership. The difference in gender between self-owned land and land that is on lease could be explained by the likelihood that male farmers have more access to land than female farmers due to cultural norms (patrilineal inheritance)[3]. This restricts women's access to land through the male relatives consistent with findings N-yanbini and Owusu-Ansah (2024). Also, female farmers mostly crop on compound farms (farms cultivated on available lands around the houses) to feed the family, though less fertile lands (McGuire, 2012; Williamson, 2021) leaving the commercial production to male farmers, hence less land is available for women to cultivate (Chigbu, 2019). The situation if not rectified is going to further deepen poverty levels of rural women with climate change predicted to worsen the plight of smallholding families in regions where agricultural production is essential (Hallegatte et al., 2016).

The few farmers that used shared leaseholds did not show any issues with adapting to climate impacts, as this study showed. A household's decision to begin soil and water conservation in response to perceived climate change, for instance, is more likely to increase with farm size. Empirical adoption studies found that farmers with larger farms have more land to distribute

[3] In a patrilineal tribe, a family's controlling spirit passes from generation to generation only through male blood lines, and these connections define one's extended family, or patriclan.

for constructing soil bunds and improved cut-off drains (Negash, 2013). But with the backdrop of global trends of increased in population growth, rapid urbanisation, and pressures of competing (non-food) land uses (Stringer et al., 2020; IPCC, 2020) in Sub-Saharan region of Africa. There is bound to be pressure on smallholders 'access to land with competing interest in land use such as for creation of residential and social amenities to cater for the rise in population (Mekasha et al., 2016; Aly et al., 2016; Bessah et al., 2019). This will require integrated policies that will cater for smallholder farmers diversifying into non-farm-based livelihoods as some studies have shown to have positive effect on well-being of smallholder farmers (Martin & Lorenzen, 2016; Chirwa et al., 2017; Danso-Abbeam et al., 2020)

The study revealed that access to crop management techniques has a positive impact on climate change adaptation by smallholder farmers consistent with findings from IPCC (2014) and Ndamani and Watanabe (2016). Farmers can make decisions in planning for their farming activities using available resources to ensure that climatic variations do not compromise crop yields. For instance, farmers are using improved crop varieties such as disease-, pest- and drought-resistant and early maturing varieties, coupled with cover cropping and mixed cropping, as adaptive practices. Farmers already adapt with both scientific and traditional technologies for crop management.

There is a negative coefficient for the knowledge of water conservation techniques that influence farmers 'decisions, as the adaptation for crop management decisions was not significant. The negative constant means farmers only minimally incorporate water conservation in their planning for the season, depending mostly on rainfall. While depending on other coping strategies like delaying planting dates to coincide with the start of rains before planting and the using of drought-resistant varieties. For example, a technique like bunding, which is exceptionally good in absorbing and conserving water for plant use, is limited to paddy rice production in the study area. This is inconsistent with other findings that showed that access to water conservation techniques has brought adaptation to climate change variations since its application is to conserve water for plant use and prevent the erosion of topsoil and leaching of nutrients from the soil (Anabaraonye et al., 2020; Eggers, 2022).

During a focus group discussion, one participant candidly explained that many farmers have become less committed to traditional farming practices, abandoning methods used by their forefathers that once supported environmental protection and high-quality crop production.

They noted that previous generations relied heavily on organic matter, such as compost and animal manure, which produced better yields. In contrast, the current reliance on inorganic fertilizers and pesticides has reduced the quality of produce. Farming is no longer the primary occupation for many, with alternative income-generating activities taking precedence. This shift, driven by time constraints and economic pressures, has led to the gradual abandonment of beneficial traditional practices.

This observation aligns with existing literature that shows smallholder farmers are increasingly diversifying into non-farm activities in response to climate variability and extreme weather (Garcia-Martinez et al., 2009; Deressa et al., 2011; Ojo & Baiyegunhi, 2020; Thindaa et al., 2020). Engaging in non-farm work helps relieve financial stress and credit limitations, enabling investment in farming inputs and adaptation strategies like adjusting planting schedules, tree planting, and using irrigation. These measures can enhance household resilience and strengthen rural economic systems.

However, achieving meaningful transformation requires an integrated policy framework that supports collaboration across formal and informal networks and encourages social learning within the broader socio-ecological system (Genovese et al., 2017; Muñoz-Ulecia et al., 2021). Without such frameworks, smallholder households may increasingly shift away from agriculture-based livelihoods altogether, or younger members may migrate to urban centers in search of work (Ackah, 2013; Antwi-Agyei et al., 2014), leading to labour shortages and further challenges for farm productivity (Abdulai & Huffman, 2014).

The household position of the respondents had the greatest probability of influencing farmers to adopt crop management techniques for climate change adaptations. Since the head of households is tasked with making decisions regarding farm activities, even on what type of crops to cultivate, most especially commercial crops, climate change adaptation is mostly decided by the head of the household rather than other members. Male farmers are less likely to adopt traditional techniques than female farmers (Antwi & Antwi-Adjei, 2023) while female heads are likely to choose diversification of income-generating activities as an adaptation since females are mostly involved in processing of produce or off-farm activities like trade (Fadina & Barjolle, 2018; Dagunga et al., 2018).

Many years of skills practice results in farmers being set in their craft, such that changing becomes difficult, since they trust what they have been practising (Yamba et al. 2019). For instance, older farmers with more years of technology experience may be more set in their ways, following the traditional ways familiar to them rather than trying out new ways of farming, while young farmers with less experience are more likely to adapt to modern technologies for the changing environment. Thus, the low adoption of modern technologies is likely due to the ageing farming population in the study zones, as young adults migrate to the southern regions for alternative jobs (Yamba et al., 2019).

The negative coefficient for the number of crops grown seasonally means that female farmers adopt several crops in a cropping season to ensure they are not all lost in the event of changing weather conditions thereby reducing risk of total crop failure within a season (FAO, 2011). Since women oversee farming to feed the family, knowing the markets and nutritional needs of the household, conversely men mostly crop for commercial purposes using mono-cropping. In support of this, Madison (2006), Tesfaye and Seiful (2016), Belay et al. (2017) reported that smallholder farmers are adjusting to climate variation using crop diversification by introducing crops that are performing well under the changing weather.

Better understanding and greater access to information by more highly educated farmers means that the adoption of scientific technologies and innovations for climate change adaptation rather than traditional ones, giving a negative coefficient. Also, since traditional practices are orally handed down from generation to generation, it does not require much education to enable the practices, but instead years of experience in practice and innovation (Yamba et al., 2019).

4.4.2 Land management adaptation

Land preparation for crop cultivation can contribute either positively or negatively to CO_2 emissions through the methods applied by farmers. The study results revealed that farmers combine different land preparation methods with the majority using either animal- or tractor-driven ploughs, which are less laborious and faster. When the onset of rainfall is uncertain, farmers need to rapidly prepare the land for sowing to meet the rains when they fall. Farmers, however, have had to abandon traditional soil water conservation practices such as raised mound use in growing sorghum and millet since it is incompatible with tractor-driven implements (Kansanga et al., 2018). This practice led to the dropping of traditional staple crops like maize, groundnut, and rice from the cropping system for commercial crops. Also, it could be argued that the increased use of tractors by farmers in clearing farmland as promoted by the New Green Revolution policy (Taiwo & Kumi, 2015) led to the exposure of smallholder farming lands to harsher climate variations. For instance, soil exposure leads to the loss of soil carbon through increased decomposition rates. More farmers continue to use tractors to cultivate land faster, leading to the abandonment of conventional land preparation methods such as slash-and-burn, raised mounds, or planting windbreaks and tree cover to conserve soil organic carbon and prevent top-soil erosion. Their plight will continue to worsen, while unknowingly contributing to CO_2 emissions by exposing topsoil to erosion as is associated with land preparation by tractor.

This is a case of the introduction and promotion of unsuitable technology adoption policies, which has led to a decline in soil fertility, resulting in a decline in crop productivity, while climate change continues to wreak havoc. However, a few farmers (13 %) used zero-till methods as a form of ‘climate smart agriculture ’to protect the soil from erosion, conserve water through effective percolation, and enhance carbon sequestration.

There was a difference between the two agro-ecological zones in the use of animal-driven ploughs, with the Sudan savanna zone using them more frequently than those in the Guinea savanna zone due to the availability and easy access of animals to perform the task. The farmers chose methods that were available and affordable to use, while considering the soil ecology and crop cultivated. For instance, rice farmers used bunding to ensure enough water in the Sudan savanna zone, while mounds are used for yam cultivation in the Guinea savanna zone to ensure easy expansion of the tubers. Farmers also complained about the cost of ploughing, which they explained is expensive, leading them to rely on the traditional use of simple tools like cutlasses and hoes for land clearance before sowing, even though it limits the farm size without help from other farmers (a traditional practice).

4.4.3 Soil management adaptation

4.4.3.1 Soil fertility improvement

Soil infertility has been one of the main challenges reported to affect smallholder agriculture in sub-Saharan Africa, and it has been exacerbated by climate change impacts (Raimi et al., 2017). Also, soil fertility improvement has become more complex as farmers need to increase fertility with the least release of greenhouse gas emissions possible, as in nitrogen fertilizers. This study has shown that farmers combine organic matter from composting, mulching, green manuring, and animal droppings with inorganic fertilizer such as NPK to improve soil fertility (Antwi-Adjei et al., 2014; Ndamani & Watanabe, 2016). However, farmers explained that improved crop varieties such as maize do not do well unless more inorganic fertilizer is used rather than organic matter. Since maize is now a major crop, inorganic fertilizer use has gradually increased in the community as a short-term trade-off to maintain yields. The continuous cultivation of improved maize and rice varieties will see a further increase in inorganic fertilizer use while the smallholder farmers' debt keeps rising due to the cost of farm inputs (incurred from an increased use of inorganic fertilizer, pesticides, herbicides, re-sowing of seeds, etc.) without the increase in yields to offset them. Also, organic matter sources such as animal droppings have become scarce, as only poultry droppings were available for purchase in the Guinea savanna zone during the 2022 cropping season.

4.4.3.2 Soil water conservation techniques

Warming trends have already become clear across the African continent with a prediction that the continent's 2000 mean annual temperature change will exceed +2°C by 2100. Coupled with these trends is the concern for the changing precipitation patterns (Pereira, 2017) as climate change and extreme weather can cause unexpected water stresses (floods and droughts) that limit agricultural productivity (Surendra & Awais, 2019; Bai et al., 2022). Accordingly, even if rainfall stays constant, the already existing water stress will be amplified due to increasing temperatures putting even more pressure on agricultural systems especially in semi-arid areas. Furthermore, since smallholder farmers depend mostly on rainwater for cultivation, there is a need to ensure enough water for crop growth during the critical stages to obtain the expected yields.

The study revealed that various methods are used based on the farmers 'experience in their agro-ecological zone, as well as the technologies available to them, such as mulching, terracing, earthing-up, ridging and irrigation. The high percentage (44.7%) of farmers not adopting soil water conservation techniques and depending solely on rainfall recorded is consistent with Matchaya et al. (2019)'s finding of indeterminate and low adoption of water conservation practices in South African rural communities.

Given the detrimental impact of climate change on rain-fed agriculture due to its uncertainty, policies aimed at maximizing the adoption of technologies to build capacity and resilience within farming systems must be implemented through social learning and co-production of knowledge (IPCC, 2014a; FAO, 2017; Ranasinghe et al., 2021). With low uptake record of agricultural innovations across the sub-Saharan African due to barriers to adoption (Meijer et al., 2015), there is a pressing need for policy processes that foster social learning and encourage actions leading to systemic changes, such as the uptake of innovations (Collins & Ison, 2009b). To mitigate the risks posed by climate change on smallholder farming livelihoods and the anticipated increase in poverty in rural areas where agriculture is economically vital, as noted by Hallegatte et al. (2016), proactive measures must be taken in Ghana.

As expected, the use of irrigation facilities was higher in the Sudan savanna agro-ecological zone than in the Guinea savanna agro-ecological zone (Table 4.4), which lacks such professionally managed facilities. But farmers that adopt irrigation have no options other than to cultivate along riverbeds or to depend on small water sources to irrigate their crops. However, women farmers in the Bole district in the Guinea savanna agro-ecological zone explained that if anybody were to construct an irrigation facility in the community, they would reject it due to the increased presence of Fulani herders (from neighbouring countries, as asserted by discussants), whose watering activities of their herds are destroying farms near water sources. It was reported that the herds trample on seedlings resulting in major losses, and the situation sometimes turns violent when the herders are confronted. It was revealed that the situation had caused farmers to develop aversive behaviour towards irrigation facilities in any form in general. This is a case of maladaptive behaviour stemming from unregulated use of water sources for agricultural production. Already Fulani herders' activities in other parts of the country have been reported turning violent with local community members (Olaniyan et al., 2015)

The use of ridges and mounds, for instance, is prevalent in the Guinea savanna because of the cultivation of yams, which requires loose soil for easy expansion of the tubers implying a lower adoption of the use of tractors than in the Sudan savanna zone. Rice farms in the Sudan savanna, for example, use bunding to retain enough water for rice growth. However, the discussions revealed that mulching materials have become scarce, leading to a decrease in their use, because the residues after harvesting are not sufficient to cover the lands to conserve soil water or prevent erosion of topsoil. This result prompts the need for a policy to bridge the gap by introducing cover crops for green manuring in place of the reduced availability of other mulch materials (Deressa et al., 2009).

The findings showed that there are more farmers (113) in the Guinea savanna zone who are just farming without adopting any strategies to adapt or cope with climate change variation, compared to the 66 farmers in the Sudan savanna zone. The non-adoption situation in the Guinea savanna zone can be attributed to challenges such as the water source situations described above or insufficient mulch materials as also mentioned above, which factor into their decisions to not practice irrigation or mulching but continue to rely on rain-fed farming. However, since mulching is one beneficial method used in conservation agriculture, an alternative such as growing cover crops can be promoted easily in place of the mulching based on a familiar practice. Also, the findings revealed that farmers are using some methods for soil water conservation or prevention of wind or water erosion without knowing their full potential. For instance, farmers from the Sudan savanna zone thought earthing-up is only for anchoring plants against being washed away by heavy rains. They were then made to think about the technology to understand why a stick shows moisture after being dipped into the mound around the plant roots.

Furthermore, according to farmers, bunding is only used for growing rice to ensure enough water for cultivation. However, the technology is being used for the regeneration of desert lands in Tanzania (Eggers, 2022). These examples show that the use of bunding can be used in water conservation for other crops and is not limited to just rice production. This traditional eco-engineering technology exists with several types found in the Upper East region designed to suit the purpose of land use, either for water conservation for cropping or the prevention of erosion. Antwi et al. (2005) recommended further research for its modification and transfer to other savanna zones especially as climate variation affects soil's ability to hold sufficient water and remain fertile. It is a sign that there is a lot more that policy must address in terms of traditional expertise and its application in similar zones to enhance the resilience of the systems using extension agents. Some traditional practices have been abandoned due to the amount of energy and time required to undertake manually. For example, composting is no longer practiced because of job diversification, which has made agriculture a secondary job.

This will further worsen food insecurity in the country, as small-holder farmers continue to be the major food crop producers.

4.4.4 Crop management adaptation

Smallholder farmers are combining traditional knowledge and scientific technologies in crop management adaptation. The findings of this study show that farmers use their farming experiences and access to various technologies when deciding adoption strategies. The difference between the two zones in how farmers adapt by using drought-resistant varieties depends on the ease of access to a source of irrigation. For example, in the Sudan savanna zone, irrigation facilities managed by Irrigation Company of Upper Region (ICOUR) are regularly maintained and made available to farmers throughout the year. In contrast, in the Guinea savanna zone, small public dams or dugouts are managed at community level (Acheampong et al., 2018), making their use subject to decision of local committee members. The focus group discussions revealed that very often a few prominent and well-connected individuals in the community have more control over the resources. There is also the case regarding the Fulani herders' behaviour around the water sources in some communities in the zone (Adomako, 2019). If there is a policy to rehabilitate small water reservoirs in communities, then it is about time that multiple stakeholders are brought together to coproduce knowledge with the aim of social learning to transform use of water resources for agricultural purposes. Bringing the various stakeholders together to discuss issues to find solutions to the access and use of water sources will enable the ironing out of difference to utilize each other’s views for collective action (Ison, 2010). This is needed since they are more environmentally friendly than big commercial dams and have the potential to boost agricultural production as an adaptive technique to enhance systems' ability to withstand shocks from changing weather conditions.

Farmers delay sowing to meet the onset of the rainy season as a mechanism to adapt to the late onset of rains (Antwi-Agyei et al., 2014; Tun Oo et al., 2017). By using their experiences of the climatic conditions over the years to predict the onset of rain, farmers can avoid resowing or filling in empty plant stands, which may be due to the failure of seed to germinate because of the lack of soil water, and thus also avoid the cost implications.

The changes to the cropping system are made to adapt to the changing climate and affect land preparation methods, as some crops may become incompatible, resulting in their abandonment. The choice to cultivate guinea corn and early millet, with a maturity period of more than three months, has decreased over the last decade due to poor yields, even though these were the main traditional staple crops for the two agro-ecological zones. Maize, (a commercial crop), suitable for cultivation with the land preparation method employed and with maturity period that fits the shortened rainfall pattern has replaced the cultivation of the traditional crops. This is consistent with IPCC (2007) report that elevated temperature associated with climate change will lead to significant regional and seasonal difference, that may require introduction of non-traditional crops as an adaptation strategy to offsite poor yield performance of traditional crops.

Undoubtedly, this has the potential to cause the loss of local germplasm (traditional crops) and the skewing of crop production, limiting farmers' choices in consumption. Farmers have also changed their food culture and the aspect of rituals, which required the use of these staples. These findings are consistent with literature Callo-Concha et al. (2012) in Ghana, Tun Oo et al. (2017) in Myanmar, Basdew et al. (2017) in South Africa and Khan et al. (2019) in Pakistan.

Additionally, practices such as mixed cropping, mono-cropping, shifting cultivation, and crop rotation are done as seasonal coping strategies to ensure sufficient yield despite the harshness of the climate impacts. These practices depend on the type of crop cultivated. For instance, in the Sudan savanna zone, paddy rice is grown using mono-cropping since it requires waterlogged land and commercial maize production. However, as already mentioned, mono-crop maize requires a high amount of inorganic fertilizer to obtain the expected yields, since any missing applications lead to substantive loss in yields. Using traditional practices such as mixed cropping, crop rotation, and shifting cultivation with fallow periods leads to soil fertility improvement, as well as pest and disease management in adapting to climate impacts as such, most farmers produce more than one crop in a season. Mixed cropping, for instance, is also used to ensure security from total loss of yields within the season in case of adversity with any of the crops. Consistent with FAO (2011) findings that farmers cultivate multiple crops to spread risk due to changing weather conditions within a season.

Shifting cultivation and fallow periods have been reported to be dwindling due to demand for land because of a population increase consistent with report by FAO (2022) and IPCC (2022), that increasing population in SSA will put pressure on land use as demand for food rises. As shown from the results, few farmers practice fallowing though they stated that it is beneficial as a practice for soil fertility regeneration. Policy direction that will build the practice in agricultural conservation through social learning could serve as a bridge that could boost adoption rate of agricultural technologies for socio ecological sustainability.

The study showed that the training of farmers through extension services was non-existent though there was a positive correlation between the few farmers who had attended training within the past five years, and the adaptation strategies practices learnt from training. The rare presence of extension agents in farming communities reflects the low adoption of technologies by farmers as knowledge transfer that leads to adoption requires training and direct practice mostly undertaking by extension officers as indicated by Angello (2015) and Sebeho and Stevens (2019).

Moreover, Drafor (2016), Angello (2017), Ameru et al. (2018) and Mapiye et al. (2019), argued that farmers decision-making is hampered by restricted information and services, increasing their vulnerability to climate impacts. For instance, the use of on-farm demonstration is recorded to have the potential to build social capital and network among farmers (Adamsone-Fiskovica et al., 2021b; Ingram et al., 2021) could be reintroduced adding up to technical learning. This may lead to the improvement of resilience of the system and eventually its transformation (Loorbach, 2010) to withstand shocks due to changing weather conditions.

Furthermore, there is the need for farmers to understand the application and benefits of technologies adopted (Schipper, 2020) to ensure application of technology is not done half-heartedly as evidence by farmers 'use of earthing-up as soil conservation practice without knowing the full benefits. Since this has the potential to lead to mal-adaptive behaviour of farmers in the form of abandonment of technologies for adaptation that will eventually deepening vulnerability of farmers. Consistent with Eusse-Villa et al. (2024) finding that certain individuals tend to maintain their patterns without changing their activities after experience an extreme weather event in mountainous region of North-eastern Italy.

Although, access to agricultural information is critical for agricultural system sustainability and output in the wake of climate fluctuations (Yaseen, 2016; Hamooya and Ngoma, 2019). However, smallholder farmers have been left on their own to figure out how to adapt to changing weather without knowing what the causes are and how long the impacts will last due to the almost non-existing interaction with extension services or public education on climate change and its impacts in the communities. This reflects in farmers' expression of fear without knowing whether traditional water conservation practices will be enough to support crop growth amidst future climate impacts. Consistent with Niang et al. (2014) and Elagib (2015) findings that the magnitude and speed of projected climatic changes will outstrip farmers' ability to manage these changes particularly in the West African Sahel region. Though farmers indicated their satisfaction with current water conservation adaptation measures, they expressed the desire to have access to sustainable irrigation facilities that can help ensure cropping all year-round.

4.5 Conclusions

This chapter established the use of both scientific and traditional methods by smallholder farmers to adapt to climate change impacts. The adoption of hybrid crop varieties (early-maturing, drought resistant, disease and pest resistant and high yielding varieties); use of irrigation on- and off-seasons; use of inorganic fertilizers and weather forecast information for decision-making as the scientific methods. Land management techniques such as bunding, earthing up and mound making to conserve soil water for plant use, use of nature symbols in weather signalling are traditional techniques used. Coupled with the use of organic materials (mulching, animal droppings, plant residue, cover cropping) to improve soil fertility and structure. Moreover, changing planting date, crop diversification, changing crop type as practices based on traditional knowledge used in adjusting to diversify risks in coping for climate variations.

Traditional knowledge is gradually losing its appeal due to lack of awareness of the full benefits of some techniques practiced by local community members, as well as the rate at which climate change is wiping-out practices based on nature for adaptation, making them less effective. Though the use of traditionally based strategies seems to be dwindling, there is no doubt that smallholder farmers will continue to use their traditional knowledge, since it is almost cost free, while it could also be the basis for policies that promote and teach various climate change adaptation strategies.

The two logistic regression models showed that farmers' adaptation decisions regarding land, soil and crop management were positively influenced by the observation or perception of weather changes, weather information (mostly traditional ways), land area available, position in the household, and crop techniques available. Education level, number of crops grown, number of plots available, water conservation techniques, gender, and agro-ecological zone had negative coefficients contrary to findings in literature.

The use of tractor- or animal- driven ploughs has become entrenched in smallholders 'land preparations, sowing at the sudden onset of the rainy season. This, however, has resulted in the loss or reduction of practices such as bunding and mound-making, which ensure the conservation of soil water for plant use, as well as certain crops that require bunds or mounds for their cultivation, since these are manually constructed, and driven ploughs are unsuitable for their preparation.

Even though traditional techniques such as bunding, earthing-up and mound-making could be used to ensure deeper soil water percolation, farmers limit their uses for certain crop production. These are gradually becoming obsolete since their practice requires manual construction, making the animal and tractor-driven implements incompatible. The situation continues with rain-fed agriculture practiced by most smallholder farmers without access to sustainable irrigation facilities. Undoubtedly, this will lead to an increase in yield losses due to water stresses and further deepening food insecurities, putting Ghana's aim of reaching SDGs 1 and 2 (No Poverty and Zero Hunger) off course.

The extremely low rate of adoption of climate change adaptation techniques as recorded in this study reflects how climate change adaptation has been promoted in the country. However, farm management decisions showed that farmers selected strategies on their own to suit the conditions they face and the availability of the techniques. Sudan savanna zone farmers adopt water conservation techniques due to its hotter and longer drought period and the availability of an institutionally managed sustainable irrigation dam while in the Guinea savanna zone the adopted crop management techniques include using drought-resistant varieties, early maturing varieties combined with public managed water sources for irrigation, a change in planting date. This situation requires integrated policy so that adaptation methods can be tailored accordingly to improve the rate of local adoption. The call for the documentation of traditional knowledge is in the right direction since it will preserve the knowledge base and prevent more knowledge from falling between the cracks or even losing its meaning as revealed during the discussions. The use of a technique without fully understanding its beneficial aspects may be one of the reasons why traditional knowledge is losing its tenets.

Farmers are introducing new crops due to mechanised land preparation practices that are incompatible with traditional mound-making for traditional crops such as millet and guinea corn cultivation. Also, with the unavailability of early-maturing varieties for the delayed onset and shortened rainfall patterns, the new crops will undoubtedly lead to the extinction of local germplasm. To adapt to climate change, the farmers 'adoption of crop systems and land preparation methods has introduced commercial crops like maize and cassava, leading to changes in their food culture and rituals, which were based on traditional staples such as millet.

According to the World Food Summit 1996, food security is obtained when the public has easy access to sufficient, safe, and nutritious food to meet their dietary requirements and provide for an active and healthy life (FAO, 1996). However, there is the need for policies that can help restore the situation, given that food security goes beyond availability, as the acceptance and variety of what is produced can have significant implications on whether it serves their needs fully or only partially.

There is a difference in land ownership between male and female farmers with female owners owning less than their male counterparts. This situation reflects on local food security since female farmers normally produce for family consumption while males are interested in commercial crops. To bridge the disparity for local food security between northern and southern Ghana, policy directions that will ensure equal access to fertile farmlands by both men and women must be pursued to curb the culture of female farmers cropping on marginal infertile lands coupled with issues associated with climate change impacts.

Smallholder farmers are gradually being pushed into debt due to costs associated with adoption of scientific technologies for climate change adaptation without the expected farm yields to compensate. The situation is moving beyond the farmers 'capacity due to costs incurred from seed, chemicals (herbicides, inorganic fertilizer, pesticides), tractor hire, and the costs of irrigation, amidst the possibility of total crop failure due to climate variations and extreme weather events.

Chapter 5

Exploring Mainstreaming Traditional Knowledge into Climate Change Adaptation Actions

Objective 5: Explore how traditional knowledge could best be mainstreamed into policy.

Research question 4: Is there a plan to mainstream and institute traditional knowledge in policy at both the district and national levels? If not, what are the barriers to this and how could they be overcome?

Abstract

Mainstreaming adaptation is adding formulated strategies to current policies and programmes to address climate concerns. Mainstreaming has been proposed as a tool for governments to ensure that traditional knowledge is utilised alongside scientific knowledge in climate change adaptation policies since scientific models alone may not be effective. Moreover, since climate change impacts differ from one ecological zone to another, adaptation strategies must be tailored specifically to address its impacts on a given ecological zone.

The chapter examines how adaptation strategies employed by small-scale crop farmers could be integrated into policy to enhance system resilience drawing on policymakers' subjective perspectives on knowledge in the policymaking process. It is based on in-depth interviews conducted with key stakeholders including members of parliament at the national level, agricultural department officials, assembly representatives, planning officers, and local NGO representatives at the sub-national level.

The findings revealed that smallholder farmers combine both scientific technologies (improved crop varieties) with traditional methods (use of organic matter for fertilisation, mixed cropping, delaying planting, fallowing, weather observation, diversification of cropping systems) in adapting to climate impacts. Also, lack of political will and resources, and limited capacity at the local level were revealed as the major barriers for mainstreaming small-scale farmers' traditional knowledge into policy. The chapter concludes that mainstreaming the strategies of smallholder farmers based on traditional knowledge and scientifically based

techniques into policy will enhance the resilience of small-scale farming system. However, for adaptation policies to be relevant to the local situation, their formulation should be prioritised using a bottom-up approach.

5.1 Introduction

Mainstreaming is the addition of aims and objectives for climate adaptation into national or sub-national policies or plans for effective planning and delivery of services. Mainstreaming climate change adaptation into development has been endorsed as a practical way to counter climate change. The paybacks include avoiding policy discord, minimising vulnerability, and increasing effectiveness, in contrast to handling climate change adaptation in a separate policy. Also, mainstreaming allows for leveraging monetary streams in sectors influenced by climate risks rather than those quotas being accessible separately for funding adaptation (Lebel et al., 2012). The close association between climate change adaptation and development has led to requests to address the two issues in a combined way. But ongoing development planning will be more viable and productive, in addition to making purposeful use of materials when climate knowledge, strategies, and actions have been integrated into the decision-making process and put forward as a single solution rather than drafting and overseeing standalone climate plans (Ayers et al., 2014). However, since adapting to changing climate patterns is imperative, integrating climate adjustment goals into current policies, in contrast to designing a dedicated adaptation policy, has been broadly promoted for public action (Runhaar et al., 2018).

5.2 Concept of mainstreaming

5.2.1 What is mainstreaming into climate change policy?

Mainstreaming refers to the integration of climate change concerns into an organisation’s existing interventions and decision-making processes. According to UNDP–UNEP (2021), it is an iterative process of embedding climate adaptation strategies into national and regional policy cycles, requiring multi-year engagement and multi-stakeholder involvement. Unlike a one-off application of climate information, effective mainstreaming is a systematic and continuous effort (UNDP, 2021).

Walker et al. (2014) describe mainstreaming as incorporating adaptation and mitigation goals across all phases of policymaking, including sectors beyond the environment, thereby reducing policy inconsistencies. Similarly, Bauer and Steurer (2013) define it as embedding climate adjustments into policy areas typically unconcerned with climate issues. The IPCC (2007) explains that mainstreaming integrates climate adaptation into broader development policies, programs, and actions, promoting more inclusive and effective decision-making. This process broadens the scope of policymaking by incorporating non-traditional knowledge sources.

Oulu (2011) defines adaptation mainstreaming as aligning climate adaptation with development planning, institutional activities, and policy decisions. He (2013) argues this approach enhances the impact and sustainability of local interventions by embedding adaptation strategies into ongoing development efforts. Integrating climate adaptation into policies and development plans can also help reduce vulnerability to climate variability and impacts.

Moreover, strengthening national initiatives and enhancing community adaptive capacity can foster sustainable development and prevent maladaptation (UNDP, 2012). Runhaar et al. (2012) highlight that mainstreaming can generate co-benefits, such as greener urban areas that reduce flood risks and support biodiversity. Kok and De Coninck (2007) add that mainstreaming can be cost-effective from both managerial and financial perspectives. When integrated into existing strategies and legal frameworks, adaptation can lead to more effective and tailored programmes. For instance, incorporating climate risk considerations into urban development plans can enhance the uniqueness and responsiveness of sectoral policies (Wamsler, 2014; Adelle & Russell, 2013).

However, mainstreaming as a strategic approach has faced criticism, particularly for its potential to reduce the visibility of climate issues and lead to policy dilution (Liberatore, 1997; Persson et al., 2016). In contrast, the standalone approach tends to rely on clearly defined responsibilities, dedicated funding, and specific legal frameworks. Therefore, for mainstreaming climate adaptation to be both effective and transformative, it must involve deliberate strategies and targeted actions that go beyond general goals.

5.2.2 Framing the concept of mainstreaming

Mainstreaming is not a new concept and has been applied as a tool for undertaking development topics such as gender inequality, HIV/AIDS, environmental degradation, and poverty reduction in developing countries (Oates et al., 2011; Lebel et al., 2012). Thus, varying frameworks for mainstreaming have been formulated based on the specific content. For instance, UNDP-UNEP (2010) interventions in mainstreaming climate change adaptation encompasses three levels:

Firstly, development efforts should purposefully target reducing vulnerability, even if not explicitly focused on climate change, while avoiding maladaptation. This approach strengthens the policy foundation for adaptation and enhances overall system resilience.

Secondly, it is essential that relevant agencies integrate climate change considerations into decision-making. This involves not only crafting climate policies but also addressing emerging needs across various sectors and regions.

Thirdly, specific adaptation policies must be introduced to address gaps overlooked by broader development and mainstreaming efforts. Achieving this requires shifts in how governments approach policymaking, budgeting, implementation, and monitoring across all levels.

However, the framework can be applied to the adaptation process or to specific elements of it, potentially intersecting with areas such as climate mitigation. Wamsler and Brink (2014) note that applying the framework to adaptation requires a comprehensive approach that systematically incorporates climate risk reduction into all procedures.

5.2.3 Understanding the drivers or barriers to climate adaptation mainstreaming

The implementation of climate adaptation mainstreaming at any stage may encounter barriers or opportunities. However, to describe the degree to which climate adaptation mainstreaming is fruitful in reference to outcomes and outputs that can be measured as successful, entails the grasping of the drivers of and barriers to mainstreaming. Earlier studies have acknowledged factors that can hinder successful mainstreaming adaptation strategies into existing policy from various viewpoints in six categories:

a. Political factors: These include alignment or conflict with adaptation goals, political will and awareness, public support, policy coherence across sectors, legislative flexibility, and government stability (Stead and Meijers, 2009; Runhaar et al., 2012; Dupont & Oberthür, 2012; Uittenbroek et al., 2012; Wamsler & Pauleit, 2016).
b. Organisational factors: Internal and inter-organisational challenges such as sectoral mandates, regulatory frameworks, coordination among government departments, collaboration across administrative levels, partnerships with non-state actors, role clarity, departmentalism, and institutional structures and processes (Persson, 2007; Stead & Meijers, 2009; IPCC, 2014; Wamsler, 2014; Uittenbroek 2014).
c. Cognitive factors: Awareness levels, perceived uncertainty, sense of urgency, and public understanding of climate issues (Persson, 2007; Runhaar et al., 2012; Biesbroek et al., 2013; Wamsler & Pauleit, 2016).
d. Resources: Availability of human and financial resources, top-level management support, efficient information flow, and sufficient technical expertise (Stead & Meijers, 2009; Runhaar et al., 2012; Ekstrom & Moser, 2014; Uittenbroek et al., 2012; Wamsler & Pauleit, 2016).
e. Adaptation challenge characteristics: The way adaptation goals are framed and integrated into sectoral agendas, clarity of objectives, and alignment of timelines (Persson, 2007; Runhaar et al., 2012; Biesbroek et al., 2013; Ekstrom & Moser, 2014).
f. Timelines: The ability to maintain momentum while awaiting long-term outcomes, and the seizing of key opportunities, such as large infrastructure projects for adaptation action (Runhaar et al., 2012; Wamsler, 2015; Uittenbroek, 2014).

Moser and Ekstrom (2010) on the other hand, outlined how various barriers and opportunities correspond to specific stages of the policy process. In the initial stage, barriers tend to be cognitive, social, institutional, or organisational, reflecting challenges in problem recognition and agenda setting. The second stage, focused on planning, is typically affected by technological, financial, organisational, or institutional constraints. In the implementation or management stage, barriers are often financial and organisational. Importantly, some challenges and opportunities may span multiple stages and reappear as the policy process unfolds. This highlights the need for an iterative, rather than strictly linear, policy approach, where past lessons inform future steps.

However, organisational barriers may not always be directly linked to climate adaptation. According to Lorenzoni and Hulme (2009) and Biesbroek et al. (2009), such barriers can include competing policy priorities, weak leadership, limited public demand, and lack of political will. Van den Brink (2009) adds fragmentation, lack of coordination, and rigid organisational cultures as contributing factors.

Nonetheless, the policy formulation process also presents opportunities. These include strong leadership, available resources, supportive public and political pressure, subsidies, alliances with innovators, and the catalytic effect of past disasters (Füssel & Klein, 2004; Jordan & Lenschow, 2010; Bulkeley, 2010; Tompkins et al., 2010). Leaders may reinterpret some barriers as potential openings or leverage conflicting perspectives as opportunities for integration (Uittenbroek et al., 2012).

5.2.4 Mainstreaming climate change policy in Ghana – the discourse

Ghana, like many African countries, has been mainstreaming various national policy frameworks in response to local and international level demands most especially the donor community to ensure that climate change adaptation and mitigation features prominently in its policies. Ghana's journey towards climate change action began in the nineties within the period between 1996 and 2014 characterised as the era of climate change and its worldwide impact. Ghana National Development Planning Commission (NDPC[4]) prepared five National Development Planning Frameworks (NDPFs). Ghana Vision 2020 from the 1996–2000 period was the first one. The Ghana Poverty Reduction Strategy[5] (GPRS I) from 2003–2005 and the Growth and Poverty Reduction Strategy (GPRS II) from 2006–2009 were prepared within the last eleven years. The NDPC has subsequently prepared three additional NDPFs: the Ghana Shared Growth and Development Agenda (GSGDA I), which covered 2010–2013, GSGDA II from 2014–2017, and the first step for Agenda for Jobs: Creating Prosperity and Equal Opportunity for All, covered 2018–2021[6], while the current NDPF, The Ghana Agenda 2027 or Ghana @ 100, covers 2022–2027. These frameworks govern the Ghanaian development

[4] The NDPC was set up under Articles 86 and 87 of the 1992 constitution authorised in making stipulations for a synchronised programme of economic and general development strategies.

[5] Ghana's development framework for economic growth, poverty reduction and human development. It is the framework adopted by the Government of Ghana to foster economic growth and fight poverty.

[6] The 2018–2021 is used as the reference MTDPF for discussions since implementation of 2022–2027 had just begun during the course of this project and most strategies were a continuation from 2018-2021.

agenda, which also includes instructions for creating medium-term development plans for metropolitan, municipal, and district assemblies (MMDAs).

The Ghana Vision 2020 framework identified environmental challenges such as pollution, deforestation, soil and coastal erosion, and inefficient waste management – a precautionary step to study "the cause of environmental degradation presents Ghana with an opportunity to avoid many of the errors committed by the industrialised countries in the past" (NDPC, 1995: 17). It aimed to decrease "ecological and environmental degradation" while promoting "an efficient waste management system and the development of water bodies to be environmentally safe in the country" (NDPC, 1995).

The GPRS I captured environmental issues linking poverty to environmental factors and declared that poverty may be triggered or worsened by exposure to environmental devastation owing to limited adoption and utilization of agricultural technologies to prevent the impacts of droughts, floods, diseases, and environmental deterioration (NDPC, 2003). GPRS I aimed at aligning national objectives with international objectives via "environmental sustainability and recuperation" (NDPC, 2003: 25). Yet, climate change was not mentioned in GPRS I, thus failing to consider its importance (Nelson & Agbey, 2005). In effect, Ghana did not feature climate matters in its development goals before GPRS II. Whereas environmental problems were expected to be part of some of the concerns for developmental planning in all sectors of the Ghanaian economy in the GPRS I period, the conspicuous non-appearance of climate formulations point to the fact that climate matters did not get much attention in the governmental plans (Owusu-Daaku & Diko, 2017).

Climate change was first evidenced in the GPRS II period with laws, objectives and tactics formulated as 'climate variability or change.' The problem was, however, framed in relation to environmental degradation with the aim to endorse the use of combined ecosystem management alongside human-centered biodiversity protection drives, and promote the use of technologies and actions beneficial to the environment. Also included were laws to protect the environment without linking the cause of environmental issues to climate change/variability (GPRS II, 2006). This prompted Cameron (2011) to indicate that the GPRS II stated general climate variability and climate change without aligning its impact to the poverty reduction strategies. Thus, Ghana's national climate change discourse only began in the GPRS

II period despite non-governmental agencies' previous engagements (Würtenberger et al 2011) while fortifying achievements towards national plans on climate change.

Climate change mainstreaming in Ghana continued with major steps in the development of national policies and actions steered by the pursuit to meet global obligations, and the demand to adjust to and ease the effects of climate change (Atanga et al. 2017). Beginning with the mention of climate change in the GPRS II plan period, the government gave 'distinct deliberation to climate change at all levels of development planning' (NDPC, 2011, 2013). The National Climate Change Committee[7] (NCCC) was established and it collaborated with the Ministry of Environment, Science, Technology, and Innovation (MESTI) to begin procedures to ensure that concerns associated with climate fluctuations were mainstreamed into the national development agenda (Würtenberger et al., 2011; Owusu-Daaku & Diko, 2017). These included the integration of climate issues into the GSGDA I and II, establishing the NCCC, developing the National Climate Change Adaptation Strategy (NCCAS), developing the National Climate Change Policy (NCCP) and the Ghana National Climate Change Master Plan (2015–2020). The GSGDA 2010-2013 (NDPC 2010) and 2014-2017 (NDPC 2014) represented substantial efforts by the government to incorporate climate change adaptation into the development agenda at the national level. The national medium-term development policy framework identified climate change concerns as intertwined and influenced the attainment of national goals and priorities. Out of the seven thematic areas of the GSGDA, climate change is discussed in four themes which are:

I. Improved competitiveness of Ghana's private sector,
II. Accelerated agricultural modernisation and natural resource management,
III. Infrastructure and human settlement development,
IV. Human development, employability, and productivity.

The GSGDA also contributed to the drive for the incorporation of climate change at the local level using guidelines of the Medium-Term Development Planning Framework (MTDPF[8]). The MTDPF: An Agenda for Jobs: Creating Prosperity and Equal Opportunity for All (First Step)

[7] The NCCC is a multi-sectoral body on climate change consisting of representatives of government and non-government institutions mandated to oversee that Ghana is guaranteed sustainable development with equitable low carbon economic growth on the tenet of climate-resiliency and compatibility with the economy.

[8] MTDPFis the framework document that gives guidelines to the national development agenda for all sectors of the economy.

2018–2021[9] also sought to augment 'climate change resilience at all levels across all sectors' by 'strengthening the incorporation of climate change in development planning and budgeting processes at all levels. Additionally, to document and broaden advanced climate-smart indigenous agricultural knowledge' (NDPC, 2017). The Ghana Agenda 2027 or Ghana @ 100 Medium-Term NDPF (2022–2027) now seeks to enhance organisational competence for successful climate-related actions, improve climate change resilience, and reduce greenhouse gas emissions by building on the tenets of the MTDPF for 2018–2021 on climate change adaptation and mitigation strategies. Figure 5.1 shows a summary of the aims for climate change mainstreaming in the Ghanaian developmental framework from 1996 to 2027.

Ghana Vision 2020: 1996-2000	• Environmental challenges: pollution, deforestation, soil & coastal erosion & inefficient waste management. • Preventive measure to understand the cause of environmental degradation.
GSGDI: 2010-2013	• Climate change at all levels of development planning. • Initiation of process to integrate climate issues in the national development agenda.
GSGDI: 2014-2017	• National Climate Change Adaptation Strategy & National Cimate Change policy document. • Mainstreaming of climate change at the local level.
Agenda for Jobs: CPEOA I: 2018-2021	• Climate change resilience at all levels & deepening mainstreaming climate change in development planning and budgeting process. • Promote and document improved climate-smart indigenous agricultural knowledge.
The Ghana Agenda 2027 or Ghana @ 100	• Enhance organisational compentence for successful climate-related actions. • Improved climate change resilience and reduce greenhouse gas emissions.

Figure 5.1: Summary of aims for climate change mainstreaming in Ghana's developmental frameworks 1996–2021. (Ghana Vision 2020, GSGDI, GSGDII, AJ: CPEOA 1st Step and Ghana Agenda 2027 or Ghana @ 100)

5.2.5 Climate change and agriculture policy nexus

There is a critical need for inter-sectoral planning and strong inter-ministerial coordination in national development regimes to ensure cohesive progress and effective climate change adaptation (Sova et al., 2014). Climate adaptation efforts should mirror this coordinated approach to build systemic resilience across the country. However, Ghana's Ministry of Food and Agriculture (MoFA) has not revised its Food and Agriculture Sector Development Policy

[9] The 2018–2021 is used as the reference MTDPF for discussions since most issues of the 2022–2027 continue from it.

(FASDEP II) since 2007, despite four successive Medium-Term Development Policy Frameworks (MTDPFs) that identify climate adaptation strategies for multiple sectors.

Sova et al. (2014) examined climate adaptation priorities in Ghana's agricultural policies and found that climate change was mentioned only once in FASDEP II, compared to 62 references in the Ghana Shared Growth and Development Agenda II (GSGDA II). This inconsistency continued, despite later frameworks such as the MTDPF 2018–2021 and the Ghana National Climate Change Policy (GNCCP) acknowledging the role of indigenous agricultural knowledge in adaptation and emphasizing the need to mainstream such practices into ministerial policy frameworks (GNCCP, 2013).

The GNCCP outlines actions to strengthen farmer resilience, including building the capacity of extension officers, promoting improved technologies, and developing climate-resilient cropping and livestock systems. These systems should include varieties and breeds tolerant to drought, flooding, and salinity. Despite this, FASDEP II remains largely silent on climate change adaptation and mitigation and fails to incorporate or even acknowledge traditional knowledge and best practices—a notable gap in aligning agricultural policy with national climate strategies (see Table 5.1). In contrast, the GNCCP implies that existing FASDEP II programmes may indirectly contribute to adaptation through science-based technologies, yet the absence of traditional knowledge integration remains a significant oversight.

Table 5.1: Comparison of climate change action programmes from the Ghana Food and Agriculture Sector Development Strategy II (2007) and the Ghana National Climate Change Policy (2013).

Food and agriculture sector development policy strategies for crop sector	National climate change policy actions for agriculture sector
Support development of certified seeds/planting materials and improve farmer usage through increasing awareness campaigns.	Enhance capacity for farmers and fisherfolk and create awareness of climate change concerns.
Deepen broadcasting of modernised technical crop production packages.	Develop and enhance the competence of extension officers in new farming technologies to deepen their support for farmers.
Promote the development of high-yielding, disease- and pest-resistant varieties, and expand distribution of accredited planting material.	Develop climate–resilient cropping and livestock systems, crop cultivars and livestock types, to withstand drought, flood, and salinity.
Guarantee to reach city agriculture workers with required information technology and inputs.	Document and advance suitable traditional knowledge and best practices.

Source: FASDEP II (2007: 42) and GNCCP (2013: 62)

5.2.6 Summary

Mainstreaming climate change adaptation involves integrating climate goals into existing national and sub-national policies and plans, aiming to enhance planning and service delivery by considering climate impacts. Instead of treating adaptation as a separate issue, it is embedded into broader development strategies. This approach provides several benefits, including avoiding policy conflicts, reducing vulnerability, and improving overall effectiveness. It also facilitates the use of resources to incorporate climate knowledge from diverse sources, encouraging public actions and engagement.

A review of policy regimes in Ghana shows a progressive effort to integrate climate change considerations into sectoral policies and development plans, in line with global trends. Institutions and frameworks have been established to support implementation. Central to these efforts is the inclusion of diverse knowledge sources, including traditional knowledge, into climate adaptation strategies, extending from the national level to sub-national, sectoral, departmental, and district policies (NCCP, 2014). However, the translation of these knowledge systems into actionable plans at the sub-national level remains limited across much of Africa, including Ghana (Atanga et al., 2017; Diko, 2018; Nkiaka & Lovett, 2018). This has led to criticisms that many policy frameworks focus more on fulfilling international obligations than addressing local needs (Cameron, 2011; Diko, 2018).

Integrating traditional knowledge into climate-related policies is especially important in African countries where rain-fed subsistence agriculture is a major economic activity and is highly vulnerable to climate change (IPCC, 2014). In Ghana, agriculture is a critical livelihood source for rural communities. However, several barriers hinder effective policy implementation, including under-resourced institutions (Chandra et al., 2018; Runhaar et al., 2018; Antwi-Agyei et al., 2021), weak collaboration among stakeholders (Diko, 2018; Naab et al., 2019; Yeleliere et al., 2022a), and a gap between climate change research and policymaking (Chandra et al., 2018; Clapp et al., 2018; Dinesh et al., 2018; Taylor, 2018). While scientific models are valuable, evidence suggests they are insufficient on their own to address climate impacts due to the localized nature of climate vulnerabilities. Therefore, integrating traditional knowledge is crucial for developing policies tailored to specific agro-ecological zones (IPCC, 2014, 2021 & 2022).

Although research has documented the role of traditional knowledge (TK) in adapting to climate change and recommended its inclusion in policy formulation (Belay et al., 2017; Antwi-Agyei et al., 2021; Apraku et al., 2021; Filho et al., 2023), a significant gap remains between scientific and traditional knowledge as policy-relevant sources of information. Policymakers in Africa often underestimate the value of traditional knowledge in climate adaptation (Leal Filho et al., 2021; Yeleliere et al., 2023). Integrating diverse interventions into cohesive policy frameworks requires contributions from various policy actors. These actors' perceptions, values, beliefs, and ideologies influence how they interpret and utilize different types of knowledge and evidence in policymaking (Lorenc et al., 2014; Cairney, 2016; Capano & Malandrino, 2022). For example, Parkhurst (2016) argues that policy actors with different belief systems may interpret the same evidence in contrasting ways due to variations in motivation and values. Additionally, the increasing complexity of communication at the science-policy interface in terms of both information quality and presentation has made collaboration among policy actors more challenging (Wilkinson et al., 2017; Sokolovska et al., 2019).

Building on this context, this chapter explores the perspectives of policy actors regarding the mainstreaming of traditional knowledge alongside scientific knowledge in climate change adaptation. It examines their views on climate change and its impacts, the adaptation strategies employed by smallholder farmers, and the role these farmers play in climate governance. Additionally, the chapter investigates the perceived barriers to integrating traditional knowledge into local climate policies.

5.3 Methodology

This part is the qualitative part of the mixed method used for the dissertation. According to Hammarberg et al. (2016) since in-depth interview (IDIs) helps to understand a condition, experience, or event from a personal perspective of individuals, the study utilised IDIs to interact with key informants/policymakers for the data collection.

The interviews were done using an interview guide developed from information from literature reviewed from climate change and development planning in Ghana. The guide was structured such that it could be answered directly by interviewees who may request to answer in written format instead of being interviewed as I anticipated that parliamentarians may complete the questions in a written fashion rather than have a one–on–one interview. The planned interviews were between 25 to 30 minutes to ensure that participants gave full attention to the interviewer although some individuals exceeded the time limit. The interviews with the parliamentarians were via phone calls though two provided answers by filling the guide as a questionnaire. The remaining interviews were face-to-face after agreeing to participate in the study (refer 2.5.3).

5.3.1 Sampling

The study utilised purposeful and snowball sampling methods for the selection of interviewees (refer to section 2.4).

5.3.2 Data collection

Data collection activity took place between May 2022 to June 2022 in the study area using face-to-face interviews for the officials participating in the study while phone interviews were done with the Members of Parliament in English language by the researcher. Though two participants of the members of parliament preferred to complete the guide as a questionnaire and submitted it in written form via WhatsApp (refer 2.5.3).

5.3.3 Data analysis

The notes from the interviews were typed out by the researcher using Microsoft Word. The typed notes with the voice recordings were transcribed, coded, and analysed using computer–aided (CAQ–DAS), NVivo 12 version (Figure 5.2). First, manual coding was done before the NVivo assisted codes were generated for the scripts and voice recordings to ensure that biases were minimised. The parent codes generated were under the following headings: Observed change due to climate change; Observed impact of climate variations in community; Sector affected the most by climate change impact; and Awareness of climate change frameworks and institutions.

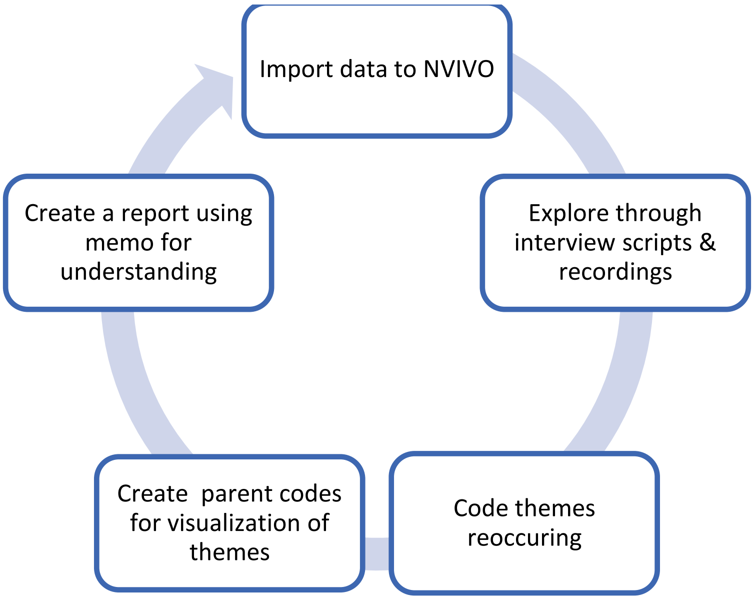


Figure 5.2: Process of identifying themes from interview scripts and recordings

Based on concept of integration for mixed method approach as intentionally mixing all components of the research process – data collection, the use of diverse methods, analysis, and presentation of results throughout all stages of the study (Creamer, 2018; Plank Clark, 2019; Zhou & Wu, 2022). This integrative feature is a defining characteristic that distinguishes mixed methods research from other multi-method or multiple study designs. A section of this chapter's results was quantified to provide a clearer understanding for readers, in line with Andrew et al. (2008), who suggest that the point of integration can be determined by the researcher to best suit the presentation of results.

5.4 Results and Discussion

5.4.1 Characteristics of Interviewees

The interviewees comprised five members of parliament (national government), seven district agriculture officers, three NGO representatives, eight district assembly members and three district planning officers (26 in total). There was only one female among the participants, reflecting the low degree of women's participation in both national and local assemblies in Ghana. Their ages ranged from 32 to 72 years, with a mean age of 47.7 (standard deviation: 12.8). Most decentralised officials comprising the agricultural officers and district assembly members were below the mean age, thus with fewer years of experience in planning and implementation.

5.4.2 Observed change in weather due to climate variations

5.4.2.1 Observed changes in weather patterns

Climate variations and their impacts have been documented by scientists seen in literature causing increase in temperature, prolonged drought, and rising sea level worldwide. According to the IPCC (2021) assessment, human activity has warmed the land, atmosphere, and ocean, causing widespread and rapid changes in the climate.

5.4.2.1.1. Changing rainfall

The findings obtained showed that all respondents had observed changes in weather conditions due to climate variations over the last ten-year period particularly with changes in the rainfall patterns as follows: delay in onset of the rainy season, shortened duration of the rainy season, high rainfall intensity, reduction in the amount and distribution of rainfall, erratic rainfall patterns as commented by a district agricultural director from Guinea savanna zone: *"Rainfall patterns have changed, with uneven distribution, fluctuating amounts, and the rainy season now ending in October instead of January previously."*

The study revealed that the length of dry spells, which typically last two to three weeks during the rainy season, has been increasing, thereby resulting in less water available for farming activities. As indicated by local NGO director from Guinea savanna zone and a district agricultural officer from Guinea savanna zone: *"Delayed rainfall pattern, rainfall duration has reduced (three months instead of four)." "Erratic rainfall patterns and seasonal shifts now bring early droughts, unpredictable rains, extended harvest times causing crop rot, and prolonged dry spells during the rainy season. The rains, which once started in March, now begin in May."* This is consistent with findings from Teye et al. (2015) and Kgosikoma et al. (2017) from a study across SSA where smallholder farmers observed decline in rainfall days.

Although, interviewees from the zones reported changes in rainfall patterns, a shortened rainy season, and a longer dry season. The impacts of these changes were different across the zones with the onset of the rainy season in May or early June and ending in September or early October in the Sudan savanna zone as explained by an assembly member: *"Delayed in* *onset of rainfall season previously starting April and now ending May or early June. The ending of the season is now in September or early October."* In contrast, the onset of the rainy season starts now in April/May and ends sometimes towards the end of September or early October in the Guinea savanna zone. The following observations were expressed from two assembly members: *"Previously, rainfall began in December or January, with the main season starting in February or March. Now, rains commence in April and may end by September. Irregular rainfall previously ended in October/November with no change in temperature."*

5.4.2.1.2. Changing temperatures

The findings revealed increase in both the daytime and night-time temperatures, and extreme weather conditions as expressed by a member of parliament: "*There is rising temperatures throughout the day."* According to the interviewees, the Sudan savanna zone has also seen an increase in both day and night temperatures while no change was observed in the Guinea savanna zone. The Sudan savanna zone has become drier due to a shorter rainy season and a longer dry season than the Guinea savanna zone as commented by an assembly member from Sudan savanna zone: *"There is increase in temperature, both day and night temperatures. Though the rainfall pattern is irregular, the most significant effect is intensity and the amount of rain, often accompanied by fierce winds."* Yaro's (2010) findings align with these observations, emphasizing that fluctuating climate characteristics result in climate change impacts—both direct and indirect—that vary across different ecological zones, livelihood groups, and sectors.

5.4.2.1.3. Prolonged drought period

The results show that the Sudan savanna zone had the longest drought period since its rainfall months (May to October) were less frequent than those of the Guinea savanna zone (April to November), consistent with district analytical reports from Ghana Statistical Services (GSS, 2014). As stated by a parliamentarian: *"The harmattan season has been prolonged making drought period longer."*

The observations from the members of parliament are similar in general terms to findings from local officials as commented by two parliamentarian interviewees: *"Rainfall pattern has changed; rains have become intense resulting in an increase in flooding."* – MP1. "*There is an increase in variability and decrease in rainfall totals alongside rising sea levels.*"– MP 2. These are the type of knowledge the members of parliament can use to advocate for, and inform the development of, climate actions to support constituents, but such actions do not happen often enough to show that parliamentarians are representing their constituents. This is not surprising since most Ghanaians view parliamentarians to be disconnected from their constituents (Acheampong, 2020) making their representation deficient. However, Fridy and Myers (2019) reported that communities rate formal national institutions (parliamentarians) as more effective in solving local problems than local institutions (district assemblies). Nevertheless, the evidence of climate variation and its impacts are major events that cannot go unnoticed, whether a disconnect exists or not.

5.4.3 Observed impact of climate variations in local communities

The results revealed that all participants observed negative impacts of climate change variations both at local and national levels. The observed impacts enumerated by the interviewees were grouped under four headings namely, environmental, economic, agricultural, and financial impacts in Figure 5.3 below.

Members of parliament primarily highlighted national-level impacts, such as perennial flooding and its economic toll, including the financial burden on citizens and the government. Relief services managed by the National Disaster Management Organisation (NADMO) further contribute to these costs. Additionally, inadequate water for hydropower generation has forced increased government spending on crude oil. These observations align with findings from Asante & Amuakwa-Mensah (2014), UNDP (2021), and the World Bank Group (2022).

In contrast, local policy actors focused on localized impacts, including altered rainfall patterns, extended dry periods, and rising farming production costs. These align with research by Zizinga et al. (2017) in Uganda, Gedefaw et al. (2018) in Ethiopia, Karachi et al. (2020) globally, and Owusu et al. (2021) in Ghana.

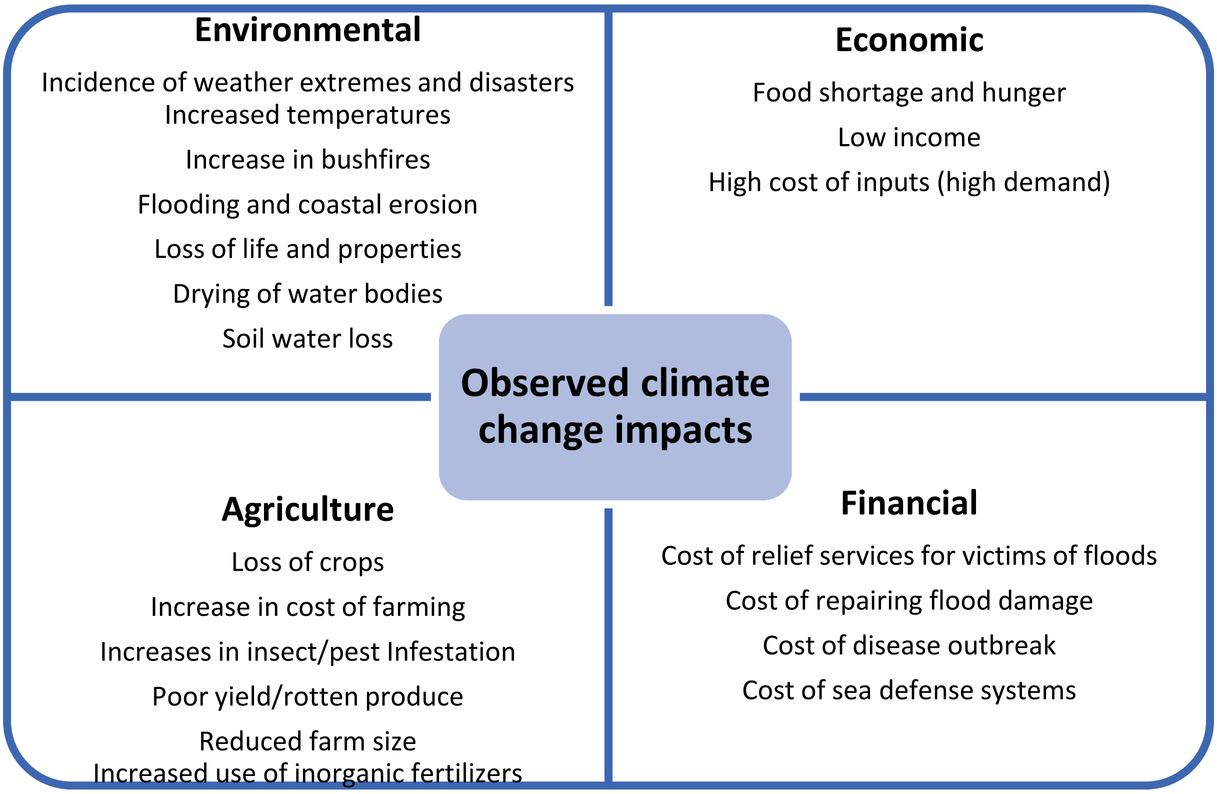


Figure 5.3: List of observed climate change impacts under four categories noted by interviewees in two agro-ecological zones in northern Ghana

Participants highlighted a range of climate change impacts across environmental, economic, agricultural, and financial dimensions. Environmentally, they observed increased flooding, occasional loss of lives and property, accelerated coastal erosion, rising temperatures, extended drought periods, and the drying up of water bodies (IPCC, 2014; 2020). Economically, they reported food shortages, hunger, declining incomes, and rising costs of agricultural inputs such as fertilizers, improved seed varieties, and tractor services. Even organic matter, which was previously free, is now sold due to high demand. A district agricultural director from the Guinea Savanna zone noted; *"The cost of production has gradually been increasing beyond farmers; even organic manure is now for sale, adding to the cost."* In terms of farming activities, participants mentioned crop losses, increased pest and disease infestations requiring chemical control, shrinking farm sizes, and declining soil fertility (IPCC, 2014). Financial challenges included the cost of relief services for flood victims and expenses for road repairs following extreme weather events (Figure 5.3).

Overall, respondents demonstrated a strong understanding of the key climate change impacts, aligning with findings in existing literature (Ndamani & Watanabe, 2016; Dendir & Simane, 2019; Khan et al., 2019; Adzawlaa et al., 2020). Notably, each group focused on issues within their mandate. However, Members of Parliament primarily addressed national-level concerns, reflecting the perception that they are often disconnected from their constituents (Acheampong, 2020), and therefore may not accurately represent local preferences during parliamentary discussions.

5.4.4 Sector affected the most by climate change

According to all stakeholders (26; 100 %), the agricultural sector is most affected by climate change, especially for smallholder farmers. This finding is consistent with Tubiello et al. (2012), who showed that subsistence food production by smallholder farmers would bear most of the brunt of climate impacts due to its dependence on rainfall for cultivation. Thus, undoubtedly, for Ghana to achieve SDGs 1 and 2 (No poverty and Zero hunger) will require intensive climate change adaptation and mitigation actions that will improve the resilience of local systems that cater to the livelihood of about 90 % of the farmers who practice smallholding farming in their communities (MoFA, 2016).

5.4.5 Agricultural sector's nationwide strategies for climate change adaptation

Since agriculture is the backbone of the Ghanaian economy, it is expected for the sector to have an aggressive strategies and campaigns nationwide to educate the teeming smallholder farmers susceptibility to the climate change impact to ensure adoption of innovations to build resilience of the farming system for sustainability. The interviewees listed the following: promotion of the use of improved cultivars; promotion of use of cover cropping and education of the effect of slash and burning as the agricultural sector's nationwide strategies for climate actions towards adaptation.

5.4.5.1 Promotion of the use of improved cultivars

Results showed that the sector is promoting the use of improved cultivars/early- maturing varieties and planting of trees interspersed with food crops (agri-silvicultural systems). In the Guinea zone, for instance, cashew and mango are being promoted in an argi–silviculture system as part of the government's Planting for Export and Rural Development (PERD)

Programme and planting for food and jobs under the government's flagship initiative (Yagbon radio online, 2020). Though the two initiatives noted above do not target climate change mitigation or adaptations, they were mentioned because they target farmers. As expressed by a coordinator for Nation Builder's Corps: "*Cashew and mango are being promoted in tree-crop production system as per the government's planting for export and rural development (PERD) programme."*

The Presidential Special Initiative (PSI), launched in 2001 by President Kufuor and the New Patriotic Party (NPP), aimed to develop Ghana's oil palm industry by adding value to palm oil products for local and regional markets, with long-term goals of accessing the global market under the United States' Africa Growth and Opportunity Act[10] (AGOA[11]) (Asante, 2012).

A similar model has been reintroduced by the current NPP administration, now focused on accessing carbon sequestration funds through tree planting. However, both initiatives primarily target large-scale farms, excluding most smallholder farmers with land sizes of only 1.5–2.0 hectares. These initiatives are often implemented by the central government without integrating into local development plans, drawing criticism for being politically motivated attempts to establish a visible presence in communities for electoral gain.

Similar patterns have been observed elsewhere in Africa. For instance, Artur and Hilhorst (2012) noted that national resources in Mozambique were allocated for political patronage. Arriola (2009), supported by Gallego and Wantchekon (2019) and Aspinall and Berenschot (2019), argued that African leaders often use patronage to reward loyalists and suppress rivals, reinforcing a top-down governance approach that marginalizes local participation. This sentiment was echoed by an executive secretary of a local NGO in the Guinea Savanna zone, who lamented the exclusion of the shea tree—an indigenous species with economic significance for women during off-farming seasons—from the presidential initiative: *"It is worrisome that the promotion of shea tree was left out of the presidential flagship initiative, the shea tree has been a source of income activities for women during off farming season since growing up. An indigenous tree that the people know very well to cultivate."* The omission of

[10] AGOA is, a unilateral United States strategic trade programme signed into law in 2000 by then President Bill Clinton to cover an eight-year period from October 2000 to September 2008.

[11] AGOA–extended to 2015 in 2004 through amendments signed by President George Bush. This builds on and expands duty-free provision of the Generalised System Preferences (GSP), offering free tariffs on 7,000 products to eligible sub-Saharan African countries exporting to the US market.

the shea tree, which has long-standing research support as an alternative to cocoa in northern Ghana, may have political motivations, as its inclusion could benefit the opposition National Democratic Congress (NDC), under whose administration the research began.

Expanding the existing shea tree research and promoting its cultivation could significantly increase local beneficiaries, particularly women. Yiridomoh et al. (2021) found that women in northern Ghana are increasingly turning to shea butter and pito production to adapt to erratic rainfall patterns. Despite this, the current initiative prioritizes cashew trees over the shea, overlooking its potential as a raw material for industrial use. A district planning officer summed up the situation: *"We are told what to do from the head office in Accra,"* highlighting the continued dominance of central government in local decision-making. Aryee (2008) also noted that the central government often imposes conditions on the District Assembly Common Fund (DACF), limiting districts' autonomy to fund locally prioritized projects. This is despite findings by Bansard and Schröder (2021) and the World Bank (2022) that community-led resource allocation can be more effective for development.

5.4.5.2 Promotion of use of cover cropping

Cover cropping has frequently been used by farmers traditionally to prevent erosion and improve soil fertility especially if leguminous crops are used as the cover crop, a traditional technique that farmers stopped using during the promotion of mono-cropping system in the 1980s for farm commercialization in the IMF/World Bank-led Structural Adjustment Program (Odutayo, 2015). The programme aim was to cultivate large farms for exportation through the promotion of increased use of inorganic fertilizers to boost farm productivity alongside the promotion of hybrid seeds in maize and cowpea production. Sub-Saharan Africa countries including Ghana have the potential to increase food production by increasing the utilization of inorganic fertilizer consumption [which as it stands is 17 kg ha^{-1} of cropland compared to a world average fertilizer consumption of 135kg ha^{-1} (AGRA, 2018)]. However, the initiative to reintroduce cover cropping by experts (extension officers) as an adaptation strategy – with advice on the selection of crop type based on the local soil type will reduce soil water loss through evaporation, and topsoil loss due to erosion, while improving soil fertility.

5.4.5.3 Educational campaign on the effects of slashing-and-burning

Interviewees noted that initiatives have been introduced to reduce the practice of slash-and-burn agriculture, a traditional land preparation method involving vegetation clearance and burning, commonly linked to shifting cultivation. Fire remains an important tool in traditional land management, especially in rural economies, where it is used for both conservation and agricultural purposes (Eriksen, 2007; Archibald, 2016; Beale et al., 2018). In savanna regions worldwide, including parts of Kenya, Africa, and Brazil, fire is employed for various cultural and economic purposes such as stimulating fresh forage growth, honey tapping, and attracting game for hunting (Mistry, 1998; Nyongesa & Vacik, 2018). In Ghana, it is valued for reducing labour in land preparation and enhancing soil fertility through ash, which provides potash (Nindel, 2017; Amoako et al., 2018). Research by Barnes et al. (2017) showed that burning significantly increased levels of exchangeable potassium (52%) and available phosphorus (82%) in the surface soil, while heat destroyed weed seeds and pest eggs (Amoako & Gambiza, 2020).

However, these fires often spread uncontrollably, especially during extended dry seasons, leading to widespread bushfires. According to the FAO (2020), wildfires and intentionally set fires destroy millions of hectares of forest globally each year, 98 million hectares in tropical zones alone, amounting to 4% of forest area loss. Ghana is among the countries most affected, losing about 75,000 hectares of vegetation annually, equating to roughly 3% of GDP (MLFM, 2006; Neequaye, 2023). As the climate continues to warm, with longer dry spells and higher temperatures, it becomes critical to enforce fire control regulations and expand public education. Horan (2020) notes that human-induced climate change began with practices like slash-and-burn agriculture, which continues to exacerbate environmental challenges.

As highlighted in Section 5.4.5, three nationwide adaptation programs in agriculture reflect Ghana's top-down policymaking approach (Imurana et al., 2014; Owusu, 2016; Appiah-Agyekum, 2020). These strategies, developed at the national level with minimal local input, are often poorly adopted at the community level. For example, the exclusion of the shea tree from current initiatives sparked concern among local actors, especially given its long-standing role in supporting women's livelihoods during the off-farming season (Yiridomoh et al., 2021). Women have developed extensive skills and traditional knowledge around shea butter processing, yet this local expertise was overlooked. Despite recognition of the value of traditional knowledge by some local policy actors, rigid implementation guidelines prevented the adaptation of programs to suit community needs.

Mainstreaming diverse knowledge sources is key to improving community resilience. Including the shea tree in adaptation initiatives, for instance, could ensure a reliable supply of quality nuts, unlike the current dependence on wild harvests. This would not only strengthen local economies but also enhance environmental and social resilience. Ultimately, moving away from rigid, top-down models toward inclusive, consultative policymaking could help communities better respond to climate risks, such as bushfires through knowledge-sharing and joint strategy development.

5.4.6 Climate change governance

5.4.6.1 Awareness of climate change framework and institution

As policies are expected to address varying national, regional, or local issues, policymakers are expected to be aware of surrounding issues including climate change and its impacts on agriculture. This section assesses how abreast the interviewees were with climate change policy implementation and institutions at national and sub-national levels.

5.4.6.1.1 Awareness of climate change policy and content

The findings revealed that majority (23/26; 87.5 %) of interviewees were aware of the existence of Ghana's climate change policy document while 3/26 (12.5 %) had no knowledge of the document. The result also indicated that 17/26 (66.7 %) of the respondents did not know about the content of the policy document, while the remaining third (9/26; 33.3 %) knew of the issues covered in the document concerning climate change mitigation and adaptation measures to be employed (Table 5.3).

When asked about the document's relevance to their work, 13 out of 26 interviewees (50%) acknowledged its importance, reflecting an increase from the 9 out of 26 (33.3%) who were familiar with its content. This gap was largely due to responses from District Agriculture Department officials, 5 out of 8 who, while not fully familiar with the document's content, still recognized its relevance. As one agricultural officer from the Guinea Savanna zone noted: *"The climate change mitigation and adaptation measures are not incorporated in the Food and Agriculture Sector Development policy document."*

Table 5.3: Categories of policy actors and their responses to CC governance awareness from two agro-ecological zones of northern Ghana

Categories	District Assembly member	Members of parliament (National)	District agricultural officials	District planning officers	Development agencies representatives (district)
Awareness of CC policy document	1110110	11111	111111	111	111
Knowledge of aspect of content of CC policy	0000000	00111	00100000	001	111
Relevance of CC policy to work/role	0000000	00111	11111000	110	111
Total interviewee category breakdown	7	5	8	3	3

Scale: 1– awareness of CC policy governance.
0 – negative awareness of CC governance.

Local government officials, under the Local Government Act of 2016, are responsible for implementing agricultural programs, delivering services to stakeholders, setting priorities, and executing plans at the district level (LGS, 2018). However, the absence of climate-related provisions in FASDEP II (2007), a key guiding document for sub-national agricultural department limits the formulation of climate adaptation strategies at the local level. As noted by a district agricultural officer; *"climate change is not captured in the FASDEP document",* this omission leads many officers to believe climate action falls outside their mandate.

Although the national Medium-Term Development Policy Framework (MTDPF) calls for integrating traditional knowledge into climate adaptation strategies, it does not provide clear directives for doing so within FASDEP II. This lack of clarity has caused regional and district officers to overlook climate actions in their planning. Yeleliere et al. (2023) similarly observed the absence of a deliberate government strategy to incorporate Indigenous and Local Knowledge (ILK) into local climate adaptation efforts.

Atanga et al. (2017) argue that Ghana's climate policy mainstreaming is largely influenced by international commitments, leaving sub-national governments without clear authority or resources to integrate traditional knowledge into development planning. Consequently, local policymakers often prioritize top-down policies that may not align with local realities or gain community support (Mabe et al., 2014). This disconnect contributes to fragmented policy implementation, hindering intended outcomes, a problem also highlighted by Imurana et al. (2014), who found that public policies in Africa often fail during implementation. Notably, also is the 12 out of 26 respondents (47.6%) that could not assess the policy's relevance due to limited familiarity with its content (Figure 5.4).

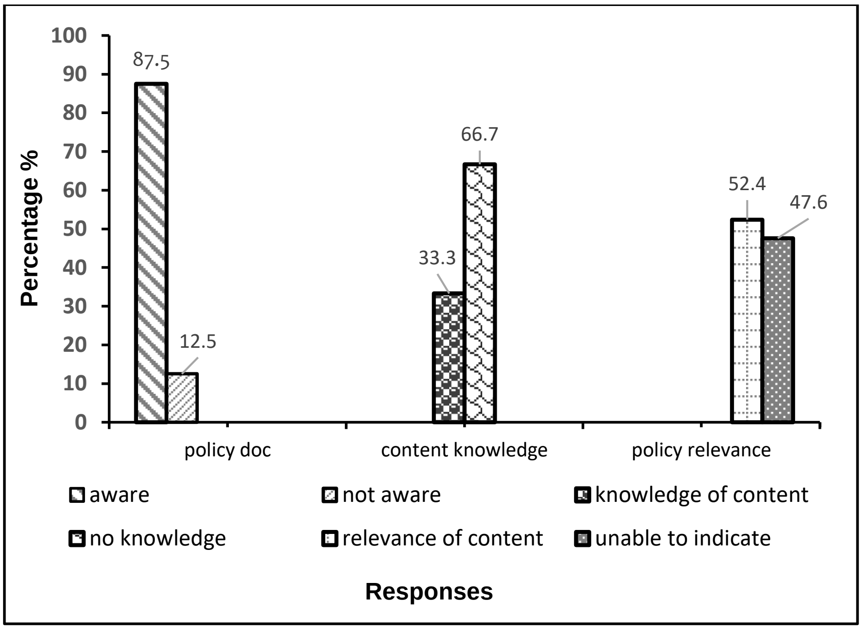


Figure 5.4: Awareness of the content and relevance of the Ghana's national climate change policy document among relevant stakeholders in two agro-ecological zones in northern Ghana

5.4.6.1.2 Awareness of ministry responsible for formulating climate change policy

The findings show that most interviewees (15 out of 26; 57.1%) were unaware of the ministry responsible for leading climate change activities. Additionally, 4 respondents (14.3%) incorrectly identified other ministries, while only 7 (25.6%) correctly named the MESTI. This suggests a widespread lack of awareness about climate change policy and leadership at the community level. This gap in knowledge was underscored by a female participant in a focus group discussion in the Guinea Savanna zone, who remarked, *"Climate change, what is it, and what do we do about it?"*

5.4.6.1.3 Knowledge of adaptation strategies used by local farmers

Much literature has shown that smallholder farmers in the developing world, including Ghana, are adapting to climate change by using their experiences generated over the years (Serra & Mckune, 2016; Belay et al., 2017; Antwi-Agyei et al., 2021; Apraku et al., 2021; Filho et al. 2023). The sub-section therefore sought to find out if the interviewees are aware of the coping or adaptation strategies used by the smallholder farmers in their local areas.

The findings showed majority (24/26; 92.3 %) of interviewees stated that farmers in their constituencies employ both traditional and scientific methods to adapt to climate variabilities while 2/26 (7.7 %) indicated the use of traditional methods only. They listed the following under the traditional methods: inter-cropping, mixed cropping, mixed farming, use of compost and manuring (animal droppings), digging of wells for dry season farming, delay in planting dates to coincide with onset of rainfall. Additionally, planting along water bodies for irrigation, use of bore holes, crop rotation, shifting cultivation, mulching, cover cropping (leguminous) and traditional methods of predicting weather as documented by Tun Oo et al. (2017), Marie et al. (2020), Devi et al. (2020) and Antwi-Agyei et al. (2021).

Among the scientific methods, the following were listed: use of early-maturing varieties, use of drought-resistant varieties, use of improved cultivars, use of inorganic fertilizers, use of tractors for ploughing, integrated nutrient management, use of agrochemicals (herbicides and pesticides), use of irrigation systems (dam or ponds) (Figure 5.5) (Ali et al., 2020), and use of minimum tillage techniques (Doku, 2018).

The findings confirm farmers combine both traditional and scientific strategies in farming as noted by respondents. For instance, they stated that farmers normally use previous weather experiences to forecast the coming season to plan their farming activities, which they opt to change if the scientific forecast convincingly predicts otherwise (although this rarely occurs). Through traditional weather prediction, the farmers delay the onset of planting their fields to coincide with the rains. Another combination comes from land preparation using animal- or tractor-driven plough, which ensures rapid land clearance ready for planting.

Figure 5.5: Pinda dam located in Kassena Nankana Municipal in northern Ghana

However, soil improvement activities such as the incorporation of organic matter to enhance soil structure and water percolation are mostly traditional. Moreover, adoption of improved crop varieties is still cultivated using traditional practices such as mixed cropping, crop rotation, and bunding to maintain yields whilst adapting to climate change impacts. For example, a respondent reported on hectares of a maize farm that failed under mono-cropping due to an inability to purchase inorganic fertilizer for a second application at the flowering stage. This situation is less likely to occur in a mixed cropping scenario, especially if it is mixed with leguminous crops such as cowpea or soya bean. This is also true for the adoption of improved crop varieties for adapting to combat climate variations. For instance, the use of the incorrect planting distance will contribute to the farmers' inability to maximise yields, which may lead to maladaptation. The prediction of cereal yield reduction due to climate change may further deepen the already poor situation. Therefore, there is a need for farmers, scientists, and policymakers to come together to co-produce knowledge that will benefit farmers and enhance the resilience of the farming system. This is consistent with Kolawole et al. (2014) and Ogallo's (2010) assertion that forming partnerships among scientists, users (multi-disciplinary) and policymakers is important to maximise the use of all available climate information, including indigenous weather indicators to coordinate decisions that are relevant to local communities.

5.4.6.2 Local governance

Local governments are designed to be independent with deliberative, legislative, and executive powers to take decisions on local affairs over their area. Yet, local governments are normally thought to be weak in governing their local area, which is attributed to low administrative and fiscal capacity; community members therefore prefer national bodies for the delivery of services (Fridy & Myers, 2019). For instance, Ghana's Local Governance Act 2016 Act 936 Article 181(1) mandated district assemblies to enact by-laws for the resolution of any functions vested to the local assemblies by the Local Governance Act or any other legislation. Also, Article 8(1) states that departments of the district assemblies are to collaborate and cooperate with non-decentralised departments, state-owned enterprises and public corporations working in the district to ensure a coordinated approach to development and management of the district to avoid duplication of efforts and ensuring a more convenient and cost-effective implementation of programmes and projects.

Furthermore, legislation requires local governments (metropolitan, municipal and district assembles) (MMDAs) to collaborate with local institutions such as chiefs, civil society groups, and non-governmental organisations operating in the local area in the regulation, supervision, promotion, and facilitation leading to the enactment of by-laws in regulation of emerging issues. However, this collaboration sometimes makes decision-making difficult especially when there is opposition by collaborating institutions, for example parliamentarians or traditional authorities. Moreover, community members view parliamentary or traditional authorities more favourably since they are acknowledged to hold more promise to deliver services as noted above (Fridy & Myers, 2019).

Sometimes, the failure to leverage entrenched institutions of traditional authority hinders the core functioning of the MMDAs due to the self-seeking behaviour that uses their cultural influence on community members. For instance, it was found that in certain parts of the Guinea savanna zone, persistent drought has led to an increase in migrant Fulani herders in the region who use the water in dams and dugouts to water their cattle as stated below by an assembly member from the Guinea savanna zone: *"The herders' water their cattle always away from where the chief's farmlands are as if they know not to go there to destroy things…"*

The situation was reported as challenging to farmers with farmlands around the water sources since the herd destroys crops during watering. This was commented by district agricultural director and an assembly member: *"Fulani Herders are destroying farmlands in the district due to watering activities of the herds."* Thus, some of the farmers around the water sources are sleeping out in the farms to prevent destruction by the cattle herds during the night, some with guns.

However, a proposed by-laws to re-locate the herders and their cattle or for herders to bear the cost of destruction of farms was rejected by the traditional rulers as explained by an assembly member from the Guinea savanna zone as follows: *"Chiefs blocked a process by the assembly to enact a law to ensure Fulani herders are made to take responsibility of the destruction of farmlands nearer to water sources within the district."*

These rulers could be considered to fall into the category of 'demons' described as a small set of public officials and individuals who engage in corrupt or rent-seeking activities, who must be dealt with for public policy to succeed, according to Aryee (2000). The *"Chiefs are favouring the Fulani herders because of 'gifts' they have received from them and also some of them are now tending their cattle for them."* as indicated by an assembly member from the Guinea savanna zone.

Furthermore, by taking caution in their decision-making process, farming lands near water bodies are left alone without cultivation to prevent the scenario of incurring losses due to the activities of Fulani herders. Thus, it reduces further the land available to farming as stated by local policy actors from Guinea savanna zone.

This was expounded when all FGD participants in Kpanyir flat out rejected the idea of having a dam ("dugout') in the community for irrigation, stating that it will attract the Fulani herders into their community with the attendant destruction of their livelihood though they acknowledge that the Fulani herders have been with them in the communities for as long as they could remember. However, recent climatic events, according to respondents, have tripled their numbers and herds of cattle, such that more farming families' livelihoods and food security are threatened. As FGD women group in consensus expressed their concerns as follows: *"We do not want dugouts in our community to attract Fulani headers (whose numbers and herds have tripled) to the community to destroy our livelihood."*

5.4.7 Mainstreaming of traditional knowledge into agricultural policy

Mainstreaming traditional adaptation techniques into development efforts, according to Mogelgaard et al. (2018), could improve the resilience of development outcomes while they ensure efficient use of resources and prevent funding that can result in unintentional maladaptation. Meanwhile, experts are advocating that the incorporation of both scientific and traditional knowledge in adaptation of climate change variabilities is the best way to build resilience in developing economies. Also, there is a broad perception with strong political backing that adaptation is a distinct situational issue ideally handled at the local level (Berkhout et al., 2015). This sub-section therefore sought the opinions of policy actors at the district level and a few at the national level on the mainstreaming of traditional strategies/techniques used by smallholder farmers into agricultural policy and at what level mainstreaming should be done.

5.4.7.1 Mainstreaming traditional knowledge into policy

The findings showed that farmers' coping/adapting strategies based on traditional knowledge as described above should pave the way for the documentation and integration of best practices into policy. This is based on assumptions that farmers have acquired considerable knowledge handed down by their ancestors or by years of farming leading to an understanding of their environment. Thus, making farmers useful sources of local knowledge could be the basis to build on for adaptation measures such as weather information. All the interviewees were of the view that the documentation and assimilation of some of this knowledge into policy will improve the agricultural systems' adaptive capacity through increased adoption of policy actions by farmers knowing they contributed to the policy formulation process. Combining diverse sources of knowledge according to Vogel et al., (2006) and Tengö et al. (2014) emerges from interaction in producing hybrid knowledge required to tackle complex problems as posed by climate change and extreme weather events. This is more so with mainstreaming as social learning process for coproduction of knowledge using multiple stakeholders in policy formulation for climate action. For instance, Schipper et al. (2022) concluded that drawing upon TK can contribute to the combined challenges of climate change, food security, biodiversity conservation and combating desertification and land degradation.

5.4.7.2 Level at which mainstreaming should be done

Since effective mainstreaming requires suitable entry points within institutional and sectoral frameworks, this subsection explored interviewees' views on the appropriate level for integrating traditional knowledge. The vast majority (25 out of 26; 96.2%) recommended that integration begin at the community level and progress incrementally through district medium-term development plans to the regional and national levels. They argued that starting locally allows for the collection of context-specific practices that can be synthesized into relevant policy. This view aligns with Berkhout et al. (2015), who emphasized that because climate impacts vary across ecological zones, locally tailored strategies are essential for strengthening adaptive capacity. Conversely, one respondent (1 out of 26; 3.8%) believed mainstreaming should start at the national level, citing better access to funding. However, they also acknowledged that effective mainstreaming would require strong cross-sectoral collaboration, with the agricultural sector taking the lead through decentralized institutions.

5.4.7.3 Barriers to mainstreaming traditional knowledge into policy

Although mainstreaming is viewed as one approach associated with (implementation) success, there still have been programmes such as gender mainstreaming and environmental policy integration that are riddled with barriers (Moser & Moser, 2005; Gupta et al., 2019). Thus, policymaker interviewees from local and national levels were asked to list foreseen barriers to mainstreaming traditional knowledge into the Food and Agricultural Sector Development (FASDEP II) policy.

The majority 22/26 (85 %) of the policy actors stated that they foresaw barriers to the implementation of mainstreaming traditional knowledge into FASDEP II. An assembly member from the Sudan savanna zone indicated that *"Political elite could be hinderance since they think uneducated farmers cannot contribute meaningfully to policy."*

Yet, another assembly member from the Guinea savanna zone stated: *"Academicians and Agric scientists may not accept information from farmers causing barriers."* in policy plans based on the integration of diverse knowledge sources. 4/26 (15%) who did not foresee any barriers arising, however, stated that mainstreaming could be done from the community to the district level without hindrance since officials needed the information for their planning and reporting purposes.

However, the list of barriers provided by the majority were categorised under four headings adopted from various authors namely, political factors, organisational factors, cognitive factors, and resource factors respectively (Uittenbroek et al., 2014; Wamsler & Pauleit, 2016; IPCC, 2014; Wamsler, 2014; Uittenbroek, 2016; Biesbroek et al, 2013; Wamsler & Pauleit, 2016). (Table 5.4).

All the interviewees mentioned financial constraints, political will, and lack of capacity at the decentralised level as potential barriers to mainstreaming activities. All the local policy actors indicated that members of parliament could pose as barriers to mainstreaming traditional knowledge into policy. Contrary to this view, the members of parliament believed that mainstreaming of traditional knowledge is a step in the right direction. Explaining further that since it will lead to the development and implementing of tailored measures required to improve farming systems' capacity to withstand climate variations. To reduce negative impacts on livelihoods and the local economy (IPCC, 2014) that may translate to sustainable economic growth nationwide.

Table 5.4: List of foreseen barrier descriptions by interviewees, categories from literature and their implications for mainstreaming traditional knowledge into climate change adaptation policy in respect of smallholder farming activities in two agro-ecological zones of northern Ghana

Barrier categories from literature references	Foreseen barrier described by interviewees	Implications on policymaking
Political factors Uittenbroek et al 2014; Wamsler and Pauleit 2016	• Lack of political will in terms of political commitment and interest. • Unsupportive attitude of policymakers. • Politicising programmes to win political points. • Lack of support from central government. • Change of government. • Ideas of some educated 'elite' members of society may hinder the promotion or implementation of ideas of farmers/local people.	Political influences such as support, commitment and interest are important in the delivery of interventions, since provision of resources (funds, personnel etc.) are decided and approved by central government.
Organisational factors IPCC 2014; Wamsler 2014; Uittenbroek 2016	• Delays due to bureaucracy. • Lack of inter-departmental collaboration such as information sharing, and bottlenecks within the system that hinder information sharing. • Lack of information flow such ineffective dissemination by extension officers. • Weak decentralised institutions: everything is ordered from central government.	Inefficient administrative systems mostly arise from a lack of collaboration between departments, inadequate flow of required information, and duplication of efforts leading to non-achievement and/or delays in delivery of goals. Thus, mainstreaming will only be effective when all departments work together.
Cognitive factors Biesbroek et al 2013; Wamsler and Pauleit 2016	• Lack of capacity at the local level (for instance, agricultural officers and local staff cannot collect appropriate data to implement mainstreaming). • Meeting conditions for proposal for funding local climate actions.	High level capacity in expertise is required for effective mainstreaming process, i.e., sensitising communities, data collection, action planning with necessary funding.
Resource factors Uittenbroek et al 2014; Wamsler and Pauleit 2016	• Financial constraints since funding at the decentralised level is extremely limited and controlled by central government. • Provision of adequate logistics, such as fuel for farm visits, seeds for farm demonstrations/activities etc.	With competing goals and activities, mainstreaming traditional knowledge into the local plans and adjustment of administration for uptake will not be feasible without provision of required resources such as personnel, funds, and logistics.

Political commitment is widely recognized by researchers as a critical driver for mainstreaming traditional knowledge into policy, as it mobilizes the necessary resources to ensure long-term sustainability across all levels. However, it also poses a risk, as changes in political leadership often lead to the discontinuation of projects initiated by previous administrations (Gyebi, 2018). For instance, President Akufo-Addo authorized the revival of a micro-hydro power project that had been stalled since 2008 following the electoral loss of his party, the New Patriotic Party (NPP) (World Energy, 2020). Given the growing urgency of climate change, political commitment must transcend partisan politics to foster inclusive collaboration and co-production of knowledge. Only then can adaptation initiatives deliver meaningful outcomes for local communities.

Prompt information flow has been identified as crucial for the farming decision-making process, which requires the input from different departments such as agriculture, education, and health to collaborate in adaptation to climate variation. Undoubtedly, the success of mainstreaming traditional knowledge requires various institutions to collaborate to remove bottlenecks to allow information flow and empowerment. Bringing the different institutions together to work towards mainstreaming traditional knowledge will build up trust, leading to the removal of obstacles from farmers during implementation.

A high level of capacity among development officials is essential for policy implementation to be effective. While adaptation cannot fully eliminate the adverse effects of climate change, it can reduce them and create opportunities for positive outcomes, particularly when guided by technically competent administrations (Füssel & Klein, 2004). Effective climate governance at the local level requires both expertise and adequate resources. However, local administrations frequently report insufficient funding, with their main source, the District Assembly Common Fund (DACF) often delayed and inadequate (Ghana Districts, 2017; Owusu–Mensah, 2015). This funding challenge is especially severe in rural districts, which lack alternative revenue sources but are home to smallholder farmers and most in need of mainstreaming efforts. These districts require financial support to restructure their administrative systems for effective adaptation.

5.4.8 Climate actions captured in district medium term development plans in the study districts.

The study results revealed that two of the study districts from the Sudan savanna zone (Kassena Nankana Municipal and West) have captured climate actions in their development plans with Kassena Nankana West training farmers on contour identification and bunding (traditional technique for water conservation and control of run-off erosion) (Table 5.5). Actions like training on climate smart action and renovation of dams were also captured under activities under the agriculture. However, districts from the Guinea savanna zone did not have any climate actions in their plans but have adopted plans from other agencies and districts to implement. Swala-Kalba-Tuna district, for instance, adopted climate action plans from their neighbouring district, Gonja East Municipal, that sought to established cashew plantation in improving carbon sinks, in addition to, sensitisation on the causes of climate change and its impacts and prevention (Table 5.5). The activities captured indicated that community input into the plans were either limited or non-existent. This could be attributed to district choice programmes that are being funded by international bodies or central government as clearly shown in the action plans (Table 5.5). The only internally generated source of funding for training of farmers in traditional techniques (contour identification and bunding) was by the Kassena Nankana West district. Thus, to be able to mainstream traditional knowledge, local government must overcome the financial hurdle to enable funding of identified local techniques to be mainstreamed into policy and plans. But, with commitment, as shown by Kassena Nankana West district, mainstreaming traditional techniques could be achieved and funded at the local government level.

Table 5.5: Description of extracts for climate actions, funding sources and status from district municipal assemblies' medium term development plan documents: 2023 implementing year from 4 districts from two agro-ecological zones in northern Ghana.

<table>
<tr><th>District</th><th>Captured Climate Action</th><th>Funding Source</th><th>Status</th></tr>
<tr><td rowspan="5">Bole</td><td>Rehabilitation of dams.</td><td rowspan="2">World Bank</td><td rowspan="5">On-going</td></tr>
<tr><td>Cashew seedling integrated land in communities.</td></tr>
<tr><td>Tree planting under Green Ghana– Forestry Commission.</td><td>Government of Ghana (GoG)</td></tr>
<tr><td>Sensitisation for covering small-scale mining.</td><td rowspan="2">District assembly</td></tr>
<tr><td>Sensitisation of illegal logging of trees for charcoal production.</td></tr>
<tr><td rowspan="6">Swala-Tuna-Kalba</td><td>Establishment of 10 hector cashew plantation in four communities.</td><td rowspan="6">World Bank</td><td>Two are on-going,
Two are yet to start</td></tr>
<tr><td>Sensitisation on the causes of climate change, and its impact and prevention.</td><td>Yet to start</td></tr>
<tr><td>Promotion of alternative livelihoods in five communities (bee keeping, cassava/gari processing, soap making and guinea fowl rearing).</td><td>On-going</td></tr>
<tr><td>Sensitisation of the dangers of bushfires.</td><td rowspan="3">Yet to start</td></tr>
<tr><td>Build capacity of staff of National Disaster Management Organisation on disaster management and prevention.</td></tr>
<tr><td>Sensitise the public on the benefits of afforestation.</td></tr>
<tr><td rowspan="2">Kassena Nankana Municipal</td><td>Construction of climate resilient and gender friendly-childcare center.</td><td>World Bank</td><td rowspan="2">New</td></tr>
<tr><td>Train 20-selected FBOs on climate smart agriculture.</td><td>Canadian Embassy</td></tr>
<tr><td rowspan="3">Kassena Nankana West</td><td>Train six farmers climate smart agriculture in 3 zones.</td><td>GoG, Others</td><td rowspan="3">On-going</td></tr>
<tr><td>Train 500 farmers on contour identification and bunding.</td><td>Internally generated funds and others</td></tr>
<tr><td>Rehabilitate five dams.</td><td>GoG</td></tr>
</table>

5.5 Conclusions

Ghana's climate change adaptation policy framework advocates for the use of the combination of the horizontal and vertical integration of objectives, goals and aims in planning for climate change adaptation (NAPF 2018). Vertical integration enables the deliberate linking of national, regional, and local level processes of adaptation framing, monitoring, and assessment (Dazé & Echeverría, 2016). Horizontal integration allows for climate change adaptation across ministries, departments, and agencies to incorporate climate change adaptation into sector development programmes. These paths provide two options for mainstreaming traditional knowledge in food and agricultural sector policies using either vertical or horizontal approaches, since, according to mainstreaming proponents, the success of integration is always achieved through an entry point in the policy process. This study shows that to reduce the many barriers that riddle the mainstreaming processes, the incorporation of traditional knowledge into the food and agriculture sector development policy should be initiated through the district level agriculture plans.

The study has shown that local policymakers are aware of climate issues and their impacts on the local environment and with community participation in the district planning process, could work towards local policies that will reflect the needs of the people. This will ensure adoption of adaptation measures captured in the local policy since studies have shown that, the introduction of foreign adaptation measures without recourse to local realities, knowhow and culture hardly make any meaningful impact due to rejection by community members (Seddon et al., 2020). Although effort to adapt to climate change as captured in the REDD + actions require the full involvement of relevant local stakeholders in both formulation and implementation of climate change mitigation and adaptation strategies at all levels (Bradley & Fortuna, 2021). However, this is not reflected in the policy discourse at the local level due to central government's flagship programmes that are announced in the districts from top – up with funding conditions. Mostly at the expense of the provision of adequate funding for tailoring of locally developed programmes for climate change adaptation. This shows major development programmes are decided at the national level with little or no input from the local level, including climate change governance.

Furthermore, the study has shown that the crop sector is most impacted by climate variability due to its prevalent subsistence nature of production. However, for subsistence farming to effectively cope with or adapt to climate variability and its impacts, it is essential to ensure easy access to suitable science-based technologies in conjunction with traditional practices.

The awareness of the policymakers to this fact will lead to the development of policies that are relevant to the local communities since such an awareness could be inferred as a form of TK knowledge acquired by observing their environment. But this is yet to influence local policies and plans to integrate TK the study has shown. since the government has no definite plans, programme and regulations aimed at traditional knowledge in local climate adaptation (Yeleliere et al, 2023). Local policy actors are not motivated to integrate TK into local strategies of sectors such as agriculture seen to be extremely sensitive to climate impacts.

Also, the study has shown that education on climate change at the local level and its impacts on livelihoods is non-existent, with the institutions responsible for it lacking the requisite capacity to facilitate the process. The policymakers, on the realisation of the potential enormity of the impact of climate change, asserted the need for collaboration in policymaking to build the adaptive capacity of local systems to enhance their resilience. They agreed unanimously that mainstreaming smallholder farmer techniques based on traditional knowledge alongside scientific techniques can enhance the resilience of farming systems, while the process would be best integrated from the ‘bottom – up.’

A shorter version of Chapter 5 has been published in W. Leal Filho (ed) Handbook of Nature-Based Solutions in Mitigation and Adaptation to Climate Change.

Chapter 6

General Conclusions and Recommendations

6.1 Introduction

Farmers have historically adapted to natural climate variability, adjusting their practices to gradual environmental shifts over time. However, human-induced climate change and global warming have intensified temperature fluctuations and altered rainfall patterns, disrupting land and water regimes that are critical for agricultural productivity, particularly in rain-fed farming systems. These changes increasingly undermine traditional farming technologies, as climate impacts vary across ecological zones. Addressing these challenges requires a collaborative approach, integrating both scientific advancements and traditional knowledge to develop locally tailored adaptation strategies and enhance the resilience of farming and food systems within local economies.

6.2 Recapping of the research aims

The research sought to identify and compile the traditional knowledge used by crop farmers in adapting to climate variations, its influence on farming activities, and how it is used in relation to‘ scientific ’methods. By answering questions about farmers' awareness of climate variations and impacts on agro-ecological zone, coping and adaptation mechanisms used in farming activities and exploring plans for integration of traditional methods into policy. Also, the potential barriers to mainstreaming TK into policy and how to overcome them in a mixed method approach in two agro-ecological zones in northern Ghana. To pursue this, the literature review distilled a set of concepts that could aid the answering of the questions. These concepts are perception of smallholder farmers (Leiserowitz, 2005; Munhall, 2008), traditional knowledge (Pareek & Trivedi, 2011; Berkes, 2012) and mainstreaming (IPCC, 2007; Lebel et al., 2012). Underpinning these concepts were the questions of farmers’ awareness of climate change and impacts on farming activities based on their perception, what influence farmers’ perception and decisions on farming practices. How farmers are coping or adapting to changing weather using TK alongside scientific knowledge for resilience of farming systems for livelihood sustainability.

The study was organised around five objectives: (i) determine the farmer-level information on the degree of observed and perceived climate changes and extreme climate variations. (ii) identify manifested climate impacts on farming practices in two selected agro-ecological zones. (iii) the various adaptation strategies used by farmers. (iv) outline the traditional knowledge used and how it augment the use of scientific methods in adaptation to climate variabilities and (v) explore how traditional knowledge could best be mainstreamed into policy. These were presented as chapters with result findings discussed in context of resilience building of smallholder farming system and livelihood and local economy for sustainability in the wake of climate change and extreme events.

6.3 General Findings and Conclusions

Main findings of the study under chapters derived from objectives.

Chapter III. Smallholder farmers perceived or observed changing climate and its impacts

The findings revealed that smallholder perceptions on the changing weather and impacts on their local ecology based on their experienced in interacting with their environment is aligned with empirical data from literature (MESTI, 2015). Farmers perceived climate change and subsequent actions are influenced by complex socio-cultural processes that determine the assessment of inherent risks and path to adaptation (IPCC, 2014).

The findings revealed differing responses from farmers in the two agro-ecological zones regarding weather patterns such as drought duration, rainfall timing and intensity, declining soil moisture, and temperature changes. This aligns with existing literature, which emphasizes that climate impacts vary across ecological zones and therefore require localized planning (IPCC, 2021).

The results highlight the need for accessible, tailored climate information and technologies to support farmers in planning for adaptation. Farmers were found to rely on both traditional and scientific sources to guide farming decisions, for example, using daily weather forecasts alongside local indicators. However, most forecasts accessed through radio or television are generic and not tailored to local farming needs. Meanwhile, previous studies suggest that when climate information is presented in user-friendly language and supported by relevant agricultural technologies, it can significantly improve productivity and guide farmers' adaptation choices (Yaseen et al., 2016; Baffour-Ata et al., 2022). Despite this, many farmers remain unsupported, with minimal education on climate change impacts and limited interaction with agricultural extension services.

The finding revealed farmers have observed localized impacts of climate change including increasing temperature, irregular rainfall patterns (amount and distributions). These have resulted in decrease in crop yields, increased incidence of diseases and pests' infestation threatening smallholder farming livelihood and local economy in general. The situation is gradually leading to deepening food insecurity and poverty for local communities as captured in IPCC 2014 regional report on impact on agricultural livelihood in Africa.

There is the need for meteorologists, extension agents, and farmers to design weather and agricultural information and advisories that are suitable for smallholder farmers to improve their uptake and utilisation. Since the effectiveness of agricultural extension agents is central to an agricultural extension system's quality, it is necessary to enhance the agents' capacity to provide appropriate services.

The chapter findings add up to scholarship on smallholder farmers' perception of climate change impacts and influence on farming decisions, including access to timely and accurate weather information, traditionally or scientifically.

Chapter IV. Traditional knowledge and climate change adaptation by smallholder farmers in two agro-ecological zones in northern Ghana:

Findings revealed that traditional knowledge is gradually losing its appeal within the study zones, mainly due to limited awareness of the full benefits of certain locally practiced techniques and the rapid rate of wiping-out practices based on nature making them less effective for adaptation to climate change. Even so, traditional knowledge has been widely recognised for its important role in climate change adaptation, resource governance, conservation, and biodiversity conservation and sustainable ecosystem use (IPCC, 2021). In addition to its potential contribution to the achievement of SDGs.

Findings revealed that smallholder farmers have been combining their traditional knowhow with scientific based technology in adapting to climate impact. Strategies such as changing crops type due to the decrease in crop yields are used to adapt to the changing climate for sustainability of livelihood. As projected in literature (IPCC, 2021) some crops can perform well under warmer temperatures, decreased rainfall, and changing rainfall patterns. Local research should be carried out on the effects of climate on the yields of traditional crops such as sorghum, millet, and rice to ensure that farmer's decision to switch crop types is based on accurate information to curb the case of maladaptation.

Findings revealed abandoning of traditional techniques for soil water conservation due to their tedious construction by farmers. Also, the change in mode of preparation of land using driven implement is not compatible with the construction of the techniques such as raised bed and mounds as noted by Kansanga et al., (2018). Thus, without access to sustainable irrigation facilities, an appropriate technology for adoption yield losses due to water stresses will increase resulting in further food insecurities, putting Ghana's aim of reaching SDG 1 and 2 (No Poverty and Zero Hunger) off course.

The findings show a difference in traditional land ownership between male and female farmers in the study zones, with females owning less land than their male counterparts. This situation impacts on local food security as female farmers typically produce for family consumption while males are mostly interested in commercial crops. Thus, to improve food security in Ghana, policy directions that ensure that both male and female farmers have access to fertile farmlands must be pursued.

There is a threat of extinction of local germplasm. Farmers are introducing new crops due to the mechanised land preparation practices that are incompatible with traditional mound-making for traditional crops, such as millet and guinea corn cultivation, and the unavailability of early-maturing varieties for delayed onset and shortened rainfall patterns.

The new knowledge revealed a gradual loss of appeal of traditional knowledge in the study communities due to climate impact leading to the dwindling of use of traditionally based strategies. This adds to information to the discourse of scholarship on the role of traditional knowledge in climate change adaptation. The implication of this knowledge on policy is for policy actions to be more locally focused due to climate specific impact on ecologies differently using traditional knowledge as basis to promote and teach various climate change adaptation strategies.

Chapter V: Exploring Mainstreaming Traditional Knowledge into Climate Change Adaptation Actions

Smallholder farmers perceived that the rapid changes in temperature and rainfall patterns over the recent decades are due to a changing climate, and these changes have impacted mostly negatively on their farming system. Adaptation efforts include changing the start of the planting date for the farming season, different land preparation methods, and choosing crops to cultivate within a farming season based on their experiences and traditional knowledge.

Although farmers adopt traditional techniques to adapt to the changing climate, the study concludes that more needs to be done by combining them with modern technologies for adaptation, which will enhance the resilience of the farming systems and the sustainability of livelihoods of farmers.

With climate impacts varying from one agro-ecological zone to another, tailored adaptation strategies must be encouraged through co-production of knowledge with collaboration from stakeholders with intended social learning (Trisos et al., 2022). This framework for mainstreaming policy actions could ensure resilience in farming systems, local ecosystems, and the livelihoods of smallholder families. The integration of traditional knowledge into policy must start from the local level through the sub-national to national levels, to ensure that policies meet the felt needs of local farmers for easy adoption.

There is a need to enhance local institutions' capacity at the sub-national level to ensure proper delivery of mandates and services to local communities. For instance, district assemblies need adequate funding for climate change education, while strengthening the climate change support delivery systems for effectiveness.

6.4 Recommendations

Based on the findings, the study recommends the following:

Research on how to enhance smallholder farmers 'capacity to manage the farming activities as a business to account for all the additional costs incurred in production due to climate change adaptation instead of seeing farming as a livelihood that is less concerned with necessary accounting measures.

There is the need for further studies on how to tailor weather information to suit the needs of farmers instead of the regular weather forecast on temperature and rainfall and form the necessary synergies (between farmers, agriculture officers and meteorologists) at the district level to produce information that will benefit the local community to adopt strategies for climate change adaptation.

Further research into whether gender influences the choice of adaptation based on traditional knowledge due to disparities found between male and female farmers' access to land and production for family consumption or commercial purposes. This can be used in policy formulation that caters to gender specific needs.

The study also recommends that further exploration of traditional technologies/techniques using ethnographic methods will give greater insight into them than questionnaires and interviews. This could further lead to re-engineering and re-introduction of useful traditional technologies that have been abandoned by smallholder farmers due to their tedious nature while using modern technology in their construction.

The study recommends that more research into traditional water conservation methods should be undertaken without adequate irrigation facilities to reduce water stresses during crop productions. For instance, the traditional engineering technique of bunding is being underutilised, only in rice production in the Sudan savanna zone, while it has been used for the regeneration of desert lands in Tanzania.

Also, further analysis of community perceptions, attitudes, and experiences can help increase understanding of how science-based measures are understood to contribute to adaptive capacity by making science-based information transmission more successful in the context of a specific community (Grunblatt & Alessa, 2017).

Finally, they study recommend further research on how local policy actors could create avenues for co-production of knowledge through collaborative partnerships between research, agricultural extension services, local authority, and communities through social learning to better inform adaptation local policies and actions.

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8.0 Appendix

8.1 Questionnaire

A. Observed and perceived climate change and impact

1. Have you experienced periods characterised by more or less favourable change in weather?
a. Yes b. No
2. Select from the list the es mentioned in Q1 above
a. low intensity rainfall b. short rainfall period c. high intensity rainfall d. irregular rainfall pattern e. increase temperatures f. decrease temperature g. long drought period h. decrease in soil moisture j. no observed/perceived es
3. In your opinion what are the causes of the changes described above?
4. Mention some of the effect of the changes on your livelihood.

B. Strategies used to adapt to climate e impact on farming

I. Land/Soil management practice/strategy
5. Have you change your land preparation recently due to changes in weather pattern for the past 10 years? a. yes b. no
6. Mention the different ways used in preparing your land for planting a. zero-tillage
b. slash and burn c. tractor-driven plough d. animal-driven plough
e. mound-making f. others
7. Out of the list mentioned above which ones have you been using regularly for the past years and why?

MaxDiff Question: Tick from the list the different ways you prepare your soil now for planting.: a. animal droppings b. mulch c. plant residues d. organic composting e. NPK (inorganic fertilizers)

8. How often do you use pesticides on your farm? a. once in a season b. twice in a season c. as often as needed. d. none
9. What technique do you use to ensure availability of water for your crops during the dry season? a. Irrigation b. mulching c. ridging d. mound-making e. terracing
10. How long have you been practicing the mentioned technique? a. <1 year b. 2–5 years c. 5–10 years d. >10 years
11. In your opinion, are they effective in ensuring enough water for the farm?
12. Has your farm size ed in the last ten years? a. increase b. decrease c. same
13. What are the reasons for the e of farm size?
II. Crop management and farm systems
14. Have you ed the type of crops you have been growing recently within the last 10 years? a. yes b. no
15. If yes, what are your reasons for changing the crop type?
16. How many crops do you plant in a season on your farm? a. 1. b. 2 c. 3 d.4
17. Describe the way you plant the different crops in the farm.
18. Why did you decide to plant that way as described in Q17?
19. When did you start planting many crops in a season/ at a time on the same farm?
a. < 1 year b. 2–5 years c. 5–10 years d. >10 years

20. Did you learned this way from someone or re-introduce old practices?
a. learned from training b. through extension agent c. traditional practices d. learned from other farmers
21. List the benefits of planting this way?
22. What other techniques/technologies have you introduced into your farming recently (5-10-year period) a. new varieties b. drought-resistant varieties c. disease-resistant varieties d. early maturing varieties e. e crop type f. new seeds g. planting date

IV. Access to weather information

23. Are you interested in weather forecast information for your farming activities?
a. yes b. no
24. What are your reasons for your answer in Q23 above?
25. From which medium do you receive scientific weather information?
a. radio b. farmer platform via mobile phone c. television d. extension service e. none
26. How do you receive the weather information?
a. daily b. monthly c. quarterly d. yearly
27. What type of information do you receive?
a. daily temperature b. rainfall date and amount c. precipitation d. wind speed e. sun intensity
28. Is the weather information explanatory and beneficial for planning your farming activities for the season?
29. Do you have any other ways to predict the weather traditionally? a. yes b. no
30. If yes, describe the various ways it is done
31. Which of the methods (scientific and traditional) do you prefer to use and why?
a. scientific b. traditional c. both
32. What are your reasons for using your selected method over the other method in Q31 above? a. accessible always b. very reliable c. irregular d. unreliable

V. Access to formal extension service

33. Have you received any agriculture (cropping) training within the last five years?
a. Yes b. No
34. From whom did you receive the training?
a. Agric extension officers b. NGOs c. farmer groups
35. What kind of training?
a. farm management b. introduction/use of new technology (new seed, resistant varieties, use of fertilizer) c. weather patterns d. proper use of fertilizer e. marketing ideas
36. In what way did the training e your farming activities?
MaxDiff Question: How satisfied are you with public authorities such as the government, municipal assembly, community level authorities with their influence over farming matters?

VI. Participation farmer-based groups/organisations (FBOs)

37. Are you a member of any farmers' groups/organisation?
a. yes b. no
38. Which group(s)/organisation(s)?
a. production (farmers) group b. credit association c. agro-processing group d. marketing group e. mutual labour support f. welfare service support g. procurement group
39. How long have you been a member?
a. < 2 years b. 2–5 years c. 5–10 years d. > 10 years
40. How has it helped in your farming activities?

41. Are some of your farming practices based on your belief (cultural or religion)? Explain.

VII. Land holding

42. How many plots of land do you have for farming?
a. 1 b. 2 c. 3 d. 4 e. >5

43. What is the size of the land you have access for cultivation?
a.< 1 ha b. 1–2 ha c. 2 -3 ha d. > 4 ha

44. Ownership type?
a. self-owned b. family land c. lease d. shared lease

C. *Biodata*

45. Sex. 1. male 2. female

46. Age of respondent. 1. 25 – 35 2. 36 – 45 3. 46 – 55 4. above 55

47. Level of education?
a. primary school b. junior secondary/high school or middle school c. secondary school d. vocational school e. tertiary f. non-formal (night school). g. others

48. Respondent's position in household
a. head of household b. member of household

49. Number of years respondent and family been farming.
a. 0–4 years b. 5–9 years c. 10–19 years d. 20–29 years e. 30+ years

50. Name of community and district

Appendix 8.2 Interview Guide

1. Gender
2. Age
3. Office

I. Awareness of climate e and its impact on farming

4. Have you observed any impacts of climate change in Ghana?
5. Kindly state the impact of climate e that you have observed and how long has it been occurring.
6. Mention the sector, in your view, that is most impacted by climate change variations.
7. Do you know how the sector is adapting to the changing weather to cope with the impact listed above?

II. Awareness of Climate Change Policy Document/use of traditional strategies by smallholder farmers

8. Are you aware that Ghana has Climate change policy?
9. Does policy have relevance on your interventions/work/duties?
10. Which ministry is at the forefront for its implementations? Linkages in the diverse ministries
11. What strategies are smallholder farmer using in adapting to climate variations in their local communities? a. traditional b. scientific methods.
12. Should the strategies mention above mainstream into the policy?
13. Which of the ministry or department's policy should the mainstreaming be done? At what level should the mainstreaming be implemented.
14. What barriers do you foresee in the mainstreaming of the identified traditional strategies?

Appendix 8.3 Focus Group Discussion Topics

Land preparation methods

- Beds
- Material used for composting/plant residues mulch. Animal droppings – type of animal domestic.
- Change of crop type: dietary es made
- Reduction temperature (low temperature) basis – dawn temp/day temp/night temperature.
- Cropping systems used – millet/cowpea/rice/vegetable
- Water conservation – no ticked: if not mound or ridges or terrace- what is used?
- Irrigation type – local water harvesting or water from dams.
- Traditional way of predicting weather: how and are they effective still.
- Importance availability of water or fertilizer.
- How farmers perceive Climate Change 'risk or threat' (worry about it; aspect that they are worried about).
- What do you expect from NGOs, district, Agric officers (extension and development officers) and national government?
- Experience with Agric extension officers.