Climate Change Vulnerability Assessment for Kassena Nankana Municipal Assembly

March 2024 | Final Report

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Photo credit: BMA

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Foreword

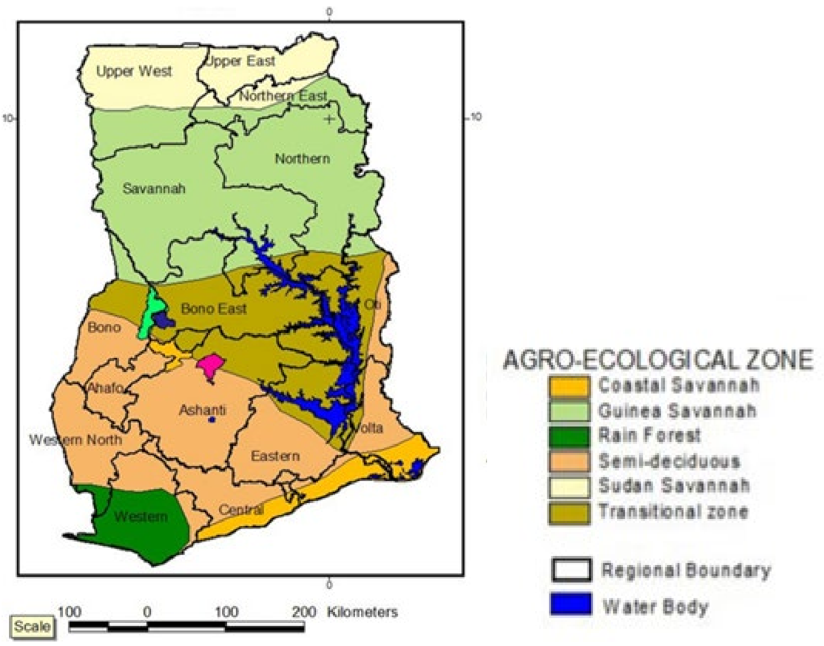
The Government of Ghana prepared six district-level climate vulnerability assessments, each for a municipal assembly located in one of the country's agroecological zones as part of the National Adaptation Planning (NAP) process. These vulnerability assessments aimed to improve the national and subnational governments' understanding of climate hazards, vulnerabilities, and risks both now and in the future to generate a knowledge base to guide adaptation planning and the identification of priority adaptation actions. They were also to provide a baseline against which progress in adaptation could be monitored and evaluated.

Vulnerability assessments were prepared for the following municipalities drawn from Ghana's six specific agroecological zones:

- Bekwai: Semi-Deciduous Forest
- Bibani-Anhwiaso-Bekwai: Rain Forest
- Cape Coast: Coastal Savannah
- Kassena Nankana: Sudan Savannah
- Kintampo: Transitional
- New Juaben South: Semi-Deciduous Forest

This vulnerability assessment was prepared for the Kassena Nankana Municipal Assembly and is representative of a district located in the Rain Forest zone (see Figure 1).

Figure 1. Regional and agroecological map of Ghana



Source: Source: Hashmiu, I., Agbenyega, O., & Dawoe, E. (2022). Cash crops and food security: evidence from small holder cocoa and cashew farmers in Ghana. *Agriculture & Food Security 11:12*, Page 7 of 21.

Table of Contents

List of Tables

List of Figures

Abbreviations

CCVA	Climate Change Vulnerability Assessment
DACF	District Assembly Common Fund
EPA	Environmental Protection Agency Ghana
GIDA	Ghana Irrigation Development Authority
GCF	Green Climate Fund
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GMet	Ghana Meteorological Agency
KNM	Kassena Nankana Municipality
IPCC	Intergovernmental Panel on Climate Change
COUR-Tono	Irrigation Company of Upper Region
MTDP	Medium Term Development Plan
MoFA	Ministry of Food and Agriculture
NADMO	National Disaster Management Organisation
NAP	National Adaptation Plan
GCF	The Green Climate Fund
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

1. About the Vulnerability Assessment Process

1.1 Introduction

The impacts of climate change have become increasingly evident in recent years across key climate-sensitive sectors in Ghana. These sectors include agriculture, fisheries, forestry, water resources, mining, health, and many others. The incidence of droughts, floods (both coastal and inland), and heatwaves have increased in many communities, with significant ramifications for Ghana's sustainable development goals. The government of Ghana, working with development partners, has initiated various efforts including the on-going National Adaptation Plan (NAP) process to identify, quantify, and understand the mediating effects of both the social and physical environments on current and future climate change impacts and their manifestations, and to respond with the appropriate adaptation measures.

As efforts to understand climate change and its impacts intensify across various sectors in Ghana, it has become crucial to assess current and plausible future climate vulnerabilities and to use such understandings to inform adaptation planning. Central to identifying, assessing, and appreciating the nature and distribution of vulnerabilities is the ability to understand the science and signs behind changing climatic conditions and the relative impacts of such changes on people, communities, and key sectors. It is also critical to use this knowledge to address uncertainties and to make bold predictions upon which actionable climate adaptation decisions will be premised.

Ultimately, effective adaptation planning should be built on a deep understanding of current and expected climate impacts and associated vulnerabilities. Conscious and purposeful processes are needed to assess, evaluate, and anticipate drivers of vulnerability across sectors and across the country's distinct ecological zones. Climate change impacts are place- and context-specific and, as such, adaptation planning should be context-responsive (Krause, Schwab & Birkmann, 2015). As Ghana's NAP process advances, it becomes critically important that adaptation planning is driven by an appreciation of the geographical distribution of current and anticipated climate impacts.

The concept of "vulnerability," which is defined here as the *propensity or predisposition to be adversely affected by climate change impacts* (Intergovernmental Panel on Climate Change [IPCC], 2022), is central to adaptation planning. An insightful understanding and appreciation of the nature and drivers of vulnerabilities in specific places and contexts is particularly helpful in the creation of context-responsive adaptation measures. There is no one-size-fit-all in adaptation planning; any effort to homogenize adaptation actions or measures will be premised on flawed understandings of climate change and its impacts across different social and ecological contexts.

Ghana's NAP process emphasizes the importance of context-specificity and place-responsive approaches to adaptation planning. A central objective, as specified in Ghana's NAP Framework (Environmental Protection Agency [EPA], 2018) is to reduce vulnerability to adverse impacts of climate change by building adaptive capacity and resilience in local communities. To achieve this, Ghana's NAP has adopted a district-focused adaptation planning process which uses district-level (third administrative level) vulnerability assessments to ground adaptation planning for key climate sensitive sectors such as agriculture (including fisheries, crops, and livestock), forestry, water, energy, gender, and health. The aim is to use information on district-level vulnerabilities and geographical considerations to develop standalone adaptation plans for each district in Ghana.

District adaptation plans will necessarily be premised on district-specific vulnerability assessments (VAs) using a common framework to flexible enough to address the unique geographies, situations, and climate impact realities of each district. Ghana's 261 districts, located in six agroecological zones, have different geographies and socio-ecological situations, so separate assessments using a shared framework provides the correct balance between analyzing each region separately and making sure those analyses are comparable. A common VA Framework provides an overarching guide for these assessments; however, by virtue of the unique differences and situations of each district, modifications may be made to suit the local realities. The process of preparing VAs has increased the Government of Ghana's knowledge base on the climate impacts threatening its districts and ecological zones and enhanced the capacity of various levels of government to undertake effective monitoring, evaluation, and learning (MEL) of the NAP process.

1.2 Purpose and Objectives of the Vulnerability Assessment

The overarching objective of the VA is to assess vulnerabilities and identify human systems, natural systems, and economic sectors in the Kassena Nankana district that are particularly vulnerable to climate variability and change and need special attention to adapt. This will help the government to make informed policy decisions when identifying adaptation actions and channeling funds for adaptation activities. The specific objectives are to:

- Identify district-specific vulnerabilities to climate change and variability and prioritize them in Kassena Nankana Municipality (KNM) to inform adaptation planning and action under the NAP.
- Inform the design of projects/programmes to be implemented in targeted districts/communities.
- Provide knowledge products that can be used for awareness creation and advocacy campaigns.

1.3 Scope of the Vulnerability Assessment

- **Sectors:** As stipulated in the Ghana NAP framework, this VA addresses a range of key sectors at risk from climate change impacts in the KNM: agriculture (crop and livestock), forestry and biodiversity, infrastructure, water, energy, and health. Impacts and vulnerabilities were assessed in individual sectors and complemented with cross-sectoral analysis that takes into consideration the cascading nature of climate change impacts.
- **Geographic scope:** This VA assessment covered the KNM and considered townships as the minimum unit of analysis. However, the township data was obtained through the aggregation of household information. The Municipality is in the Sudan Savannah agroecological zone.
- **Timeframe for analysis:** Given the long-term nature of climate change and its impacts, the VA examined current vulnerabilities as well as projected future expected impacts up until 2100. This approach provided important information for planning into the future.

1.4 Outputs of the Vulnerability Assessment

This VA produced the following outputs, which are elaborated in the sections in the report indicated in parenthesis in the list below:

- Output 1: Development of climate projections and scenarios for the Kassena Nankana district (4.4)
- Output 2: Description and creation of representative district-level vulnerability narratives (4.3)
- Output 3: Projections and description of potential future vulnerabilities (4.4)
- Output 4: Analysis of pathways that link current vulnerabilities to the future (4.3 and 4.4)
- Output 5: Description of prioritized vulnerabilities in key climate-sensitive sectors (4.3)
- Output 6: Creation of a map of vulnerability hotspots in each district (4.3)
- Output 7: Identifying available options to help people and communities adapt to the effects of climate variability and change (4.3)

1.5 Guiding Principles

Development of the vulnerability assessment for the KNM was guided by the following principles:

- **District-specific and needs-driven**: The assessment was tailored to identify specific vulnerabilities in the districts to inform the development of district-specific adaptation responses to the impacts of climate change and variability. Specific vulnerabilities, needs, and adaptation responses of the KNM were obtained through key informant interviews and stakeholder workshops.
- **Inclusivity**: The VA process was designed to consciously identify, engage, and include all institutions, sectors, communities, and vulnerable groups (including women, youth, and marginalized stakeholder groups) who are currently impacted or projected to be impacted by climate change. Seventeen women and 28 men were engaged in workshops to provide input for the design and preparation of the VA. (See Appendix 4 for a list of stakeholder organizations represented in the workshops.)
- **Relevant to the NAP and national priorities**: The VA process was aligned with and advanced Ghana's NAP process, as well as other national and KNM development priorities. The VA incorporated sectors and areas of developmental priority in KNM's Medium Term Development Plan (MTDP) and considered how the results of the VA could inform actions in such areas.
- **Utilize existing structures and resources:** The Green Climate Fund (GCF) NAP Readiness program has been running in Ghana for some time and has generated knowledge, established stakeholder relationships, and built collaboration fora. The VA process utilized these existing structures wherever possible and appropriate, such as working with the KNM to facilitate key informant interviews and stakeholder workshops. Such an approach saved time and costs, strengthened existing structures, and helped to ensure sustainability of this and future VA exercises**.**
- **Gender-sensitive approach:** The VA process sought to understand and consider the different rights, roles, and responsibilities of women and men in the community and the relationships between them in the context of vulnerability to climate change and hazards. Gender-sensitive vulnerability analysis implies that both qualitative and quantitative data used in the vulnerability assessment, disaggregated by gender and age, has been gathered and analyzed. This is in recognition that vulnerable groups (either by age, capabilities, gender, or economic standing) are affected in different ways by climate change and that these differentiated vulnerabilities must be integrated into the analysis. Both men and women should be consulted together and separately, for example in focus group discussions, about their perception of climate change, risks/hazards, and current and potential impacts of climate change on livelihoods and well-being. The government of Ghana has already produced a gender assessment of its NAP process, which is drawn upon in the VAs. This guiding principle was realized in this VA by ensuring a balance in gender representation during stakeholder workshops and household surveys.

1.6 Definition of Key Terms

The terms and definitions for this VA are adopted from the IPCC's Sixth Assessment Report (AR6) (IPCC, 2022) and are listed below:

- **Adaptation** is defined, in human systems, as "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or take advantage of beneficial opportunities." In natural systems, adaptation is "the process of adjustment to actual climate and its effects; human intervention may facilitate to moderate harm or take advantage of beneficial opportunities."
- **Exposure** is defined as "the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected by climate impacts."
- **Vulnerability** is "the propensity or predisposition to be adversely affected" by climate change impacts and "encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."
- **Sensitivity** refers to "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise)."
- **Adaptive capacity** refers to "the ability of a systems, institutions, humans and other organisms to adjust to potential damages, to take advantage of opportunities, or to cope with the consequences" of climate change – including climate variability and extremes.

1.7 Methodological Framework for the VA Process

Kassena Nankana Municipal Assembly's vulnerability assessment adopted a blend of top-down and bottom-up approaches – also known as the hybrid approach. This approach is recommended by the LDC Expert Group's NAP technical guideline (LDC Expert Group, 2012). Top-down approaches focus mostly on the biophysical impacts of climate change but say less about why, which, and how people are vulnerable. Bottom-up approaches, on the other hand, mainly provide information about the vulnerability of different social groups and discuss the inherent characteristics of the system that make these groups and their context vulnerable to climate change. Comprehensively assessing vulnerability to climate change required an integration of both approaches.

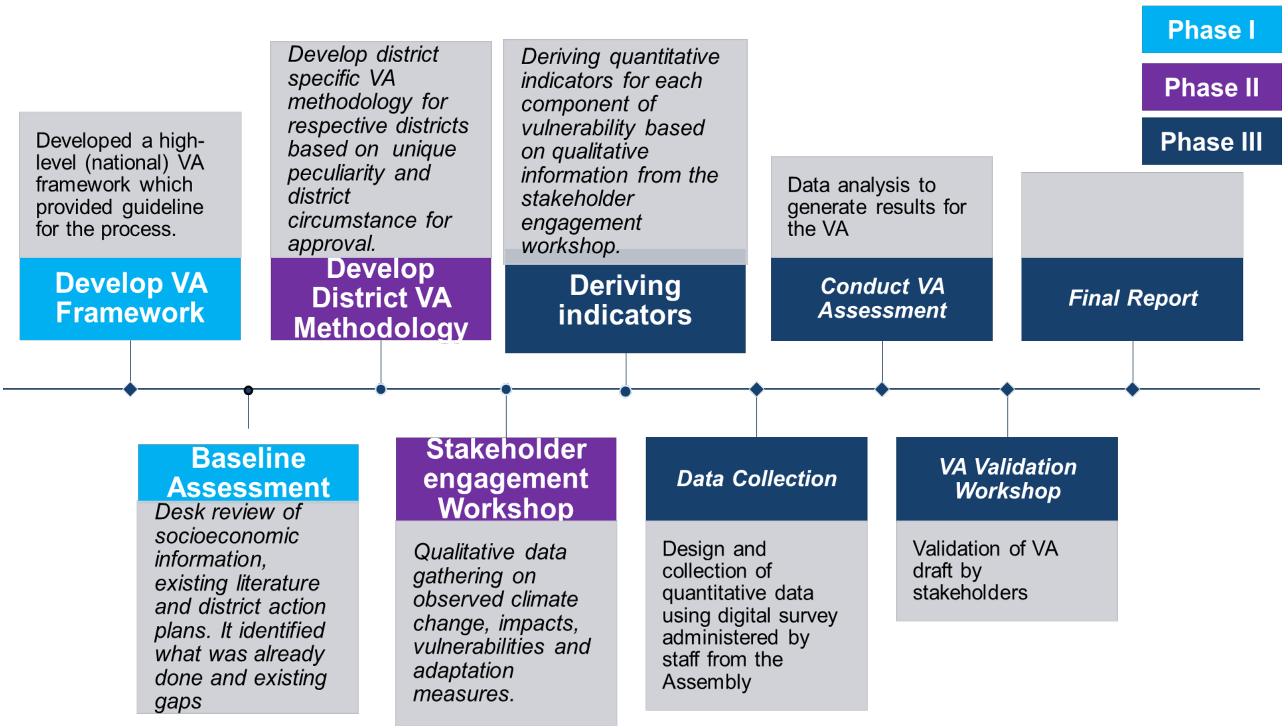
In this VA, climate modeling constituted the top-down approach. The bottom-up approach sought to answer the following questions:

- Who or what is vulnerable to climate and non-climate stressors?
- Where is someone or something vulnerable within the municipality?
- When is someone or something vulnerable?
- Why and how is someone or something vulnerable?
- How important are climate stressors relative to non-climate stressors?

The minimum mapping unit for the assessment was the household, which was aggregated into the village/town unit. The approach assessed vulnerability of the priority sectors indicated in the Ghana NAP Framework at the district level and zoomed in on agriculture and fishing at the town level. This assessment therefore adopted the Climate Vulnerability and Capacity Analysis tool developed by CARE International (2019), which provided a framework and instructions for the VA team to gather and analyze vulnerability information at the community level, to develop socio-economic and climate change scenarios, and to carry out top-down vulnerability assessments in individual sectors (such as coastal resources, water resources, agriculture, and human health).

The VA process adopted a three-phase approach to deliver its expected outcomes. A report was prepared and submitted for each Phase and the output informed the next phase. The activities in each phase are summarized in Figure 2 below.

Figure 2. The vulnerability assessment process



1.7.1 Institutional Arrangements and Stakeholder Engagement Plan

Climate change is an existential problem that affects people and systems differently. Addressing a problem of the magnitude of climate change requires collective action. It becomes imperative, therefore, that conscious efforts are made to engage relevant and diverse stakeholders. Such an approach seeks to deploy an engagement and consultation arrangement that not only serves the purpose of the VA, but also prepares all stakeholders to acquire the requisite knowledge to build adaptive capacity and participate fully and effectively in subsequent adaptation planning processes in the Kassena Nankana Municipality. The stakeholder engagement plan is strategically aligned to the Ghana NAP's institutional engagement plan, which aims to develop and cultivate local ownership of the adaptation planning process (EPA, 2018).

The stakeholder engagement process involved identifying key relevant stakeholders within the district, establishing their roles and responsibilities regarding climate action, and understanding their challenges or opportunities in engaging in climate actions. It also considered the best possible and most convenient approaches to engage all identified stakeholders. Working in close collaboration with the Local Government Team, especially the Planning Unit of the Municipality, various entities and interest groups within the district were identified and engaged in different ways (Appendix 2). Participatory workshops and consultations were used to engage stakeholders. This approach facilitated collaboration, ownership, learning, and knowledge refinement through dialogue. Stakeholders identified are the ones that will be affected (positively or negatively) by climate risk and impacts in the community.

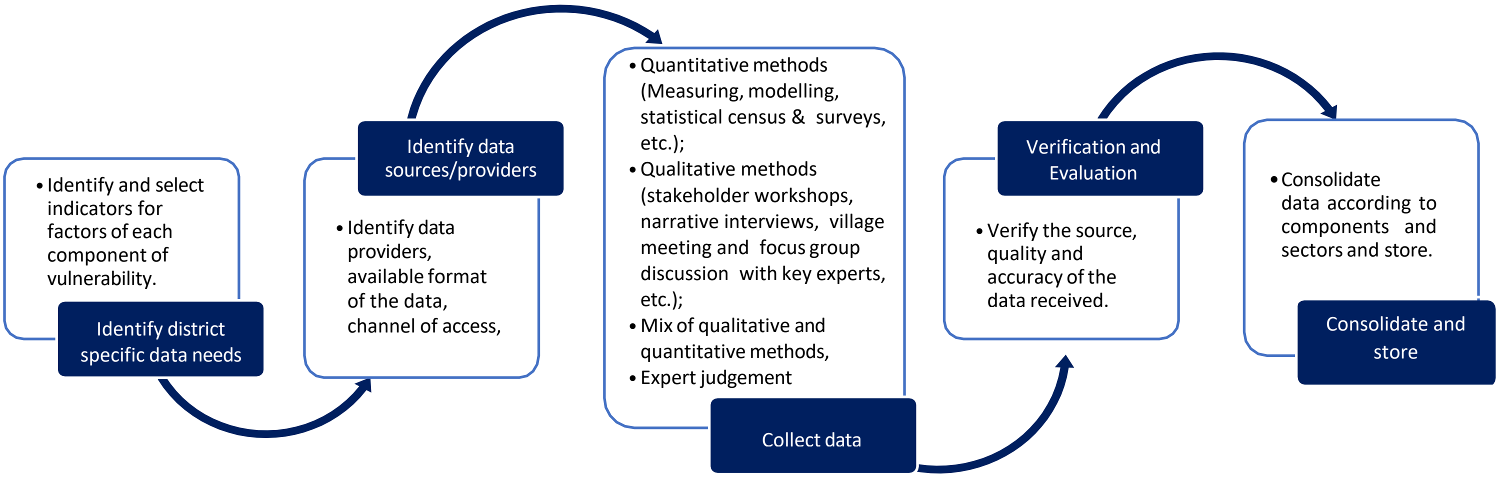
1.7.2 Ensuring Gender Responsiveness

The assessment process ensured that gender-sensitive vulnerabilities captured and highlighted through (i) inclusion of 21 women and 36 men in the stakeholder engagement process (ii) creation of subsections for gender vulnerabilities; and (iii) discussing how sector impacts are linked to specific gender issues.

1.7.3 Methodology for Data Gathering and Management

Key to the VA is data collection and management. Figure 3 summarizes the approach to data collection.

Figure 3. Data collection framework



The methodology for data collection entailed:

1. **Desk review:** The review aimed to understand what information existed and where there were gaps. The initial desk review undertaken in Phase 1 provided a good overview of climate and vulnerability data in Kassena Nankana Municipality.
2. **Stakeholders and experts' consultation:** Experts at the national, regional, district, and local level were consulted to collect and verify information and data.
3. **Stakeholder engagement workshop:** The initial stakeholder workshop was used to collect data on prevailing climate change, impacts, vulnerabilities, and impacts; and the validation workshop was used to validate the final vulnerability assessment report.
4. **Household-level survey:** A digital questionnaire was administered to households by trained enumerators (primarily staff from the Municipal Assembly) to collect data for the indicators for the vulnerability assessment.

2. District Profile

The information in this section is predominantly derived from a baseline vulnerability assessment conducted by the Environmental Protection Agency (EPA), which constituted the first phase of the assessment. A copy of the report can be obtained from the EPA.

2.1 Geographical Location and Size

The Kassena Nankana Municipality (KNM) is located in the western part of the Upper East Region of Ghana. It lies between latitudes 11°10’ and 10°3’ north and longitude 10°1’ west of the meridian. The Administrative Capital of the municipality is Navrongo. Other prominent towns include Kologo, Pungu, Pindaa, and Naaga. It is one of the northernmost districts in the country, sharing a boundary with Ghana’s neighbour Burkina Faso to the north; with Bongo and Bolgatanga Municipal to the east; West Mamprusi District to the south; and Builsa South, Builsa North and Kassena Nankana West districts to the west. The Municipality has a total land area of 865 km^2. It is divided into nine zonal councils: Navrongo, Naaga, Manyoro, Yua, Biu, Doba, Sirigu, Telania, and Northeast.

2.2 Administration and Governance

The governance structure of the Municipality comprises a general assembly, executive committee (and sub-committees), coordinating directorate, and decentralized departments.

The highest decision-making body is the General Assembly, comprised of 52 members. 35 members are elected by popular vote, 15 are appointed by the President, and the other 2 are a member of Parliament and the Chief Executive. The General Assembly performs deliberate, legislative, and executive functions under the leadership of the Presiding Member, who is elected by two-thirds of all Assembly Members. The Chief Executive is also appointed by the President but must be approved by two-thirds of all Assembly Members.

The Executive Committee (EC) and associated sub-committees are the mode through which the activities and functions of the Municipality are carried out. Examples of sub-committees that work under the supervision of the EC are development planning; agriculture, environmental and climate change; women and children; medium and small-scale enterprise, etc. These sub-committees work together to implement the Municipality’s development plans. Specifically, the environment and climate change sub-committee is primarily responsible for developing and supervising the implementation of the environmental and climate change components of the Municipality’s Medium Term Development Plan (MTDP). Meetings of the EC are chaired by the Chief Executive, while meetings of sub-committees are chaired by a chairperson who is elected from among the members at the first meeting.

2.3 Community Organizations/Non-State Actors

Local and international non-governmental organizations (NGOs) are key development actors who partner with the government through state institutions to implement interventions to enhance the adaptive capacity and resilience of vulnerable populations. There are several of such organizations in the KNM that have partnered with government to improve the living standards of the inhabitants of the municipality. The high number of NGOs is partly due to the municipality's high vulnerability to climate change and the need for sustained interventions. Some NGOs operating in the municipality include the Center for Social Mobilization and Sustainable Development, the Institute for Social Research and Development, Participatory Action for Rural Development Alternatives, Rural Initiatives for Self-Empowerment Ghana, and Link Community Development. Many of these organizations are currently implementing projects around capacity building, education, health, local economic development, and agriculture.

2.4 Physical and Environmental Features

Physically, the municipality is generally low-lying with an undulating landscape and isolated hills rising to about 300 metres in the west. These hills include Fie (280 metres), Busono (350 metres), and Zambao (360 metres). The generally low-lying relief of the municipality provides an opportunity for developing infrastructure such as roads and powerlines at a relatively low cost. It also means the cost of building is relatively low due to low landscaping costs compared to municipalities that have steep slopes and unstable soils. In terms of agriculture, the low-lying landscape enables easy tillage of lands.

The municipality's drainage system is constituted mainly around the tributaries of the Sissili River: the Asibelika, Afumbeli, Bukpegi and Beeyi. The dam for the Tono irrigation scheme is constructed on a tributary of the Asibelika River (the Tono River), which is of great economic importance to the entire municipality. Two main types of soils, the savannah ochrosols and groundwater laterite, are present in the municipality. Most of the municipality's soil is groundwater laterite, while the northern and eastern parts of the municipality are covered by savannah ochrosols. The savannah ochrosols are porous, well drained, loamy, and mildly acidic and interspersed with patches of black or dark-grey clayey soils. This soil type is suitable for cultivation and accounts for the municipality's arable land, including most parts of the Tono Irrigation Project site where both wet (rainfed) and dry season farming activities are concentrated. The groundwater laterites are developed mainly over shale and granite and cover approximately 60% of the municipality's land area.

The municipality lies within the Guinea Savannah agroecological zone. This zone is covered mainly by Sahel and Sudan-Savannah type vegetation comprising mainly of savannah grassland with short trees and shrubs. Common trees found are dawadawa, baobab, shea nut, and mango. The vegetation type is conducive for animal rearing, especially small ruminants (e.g., sheep, goats) and poultry. However, anthropogenic activities over the years have affected the original (virgin) vegetation cover. Vegetation is important because it affects soil development over time, generally contributing to a more productive soil; and provides wildlife habitat, food, direct and indirect socio-economic products and services for humans, as well as spiritual and cultural experiences to some people.

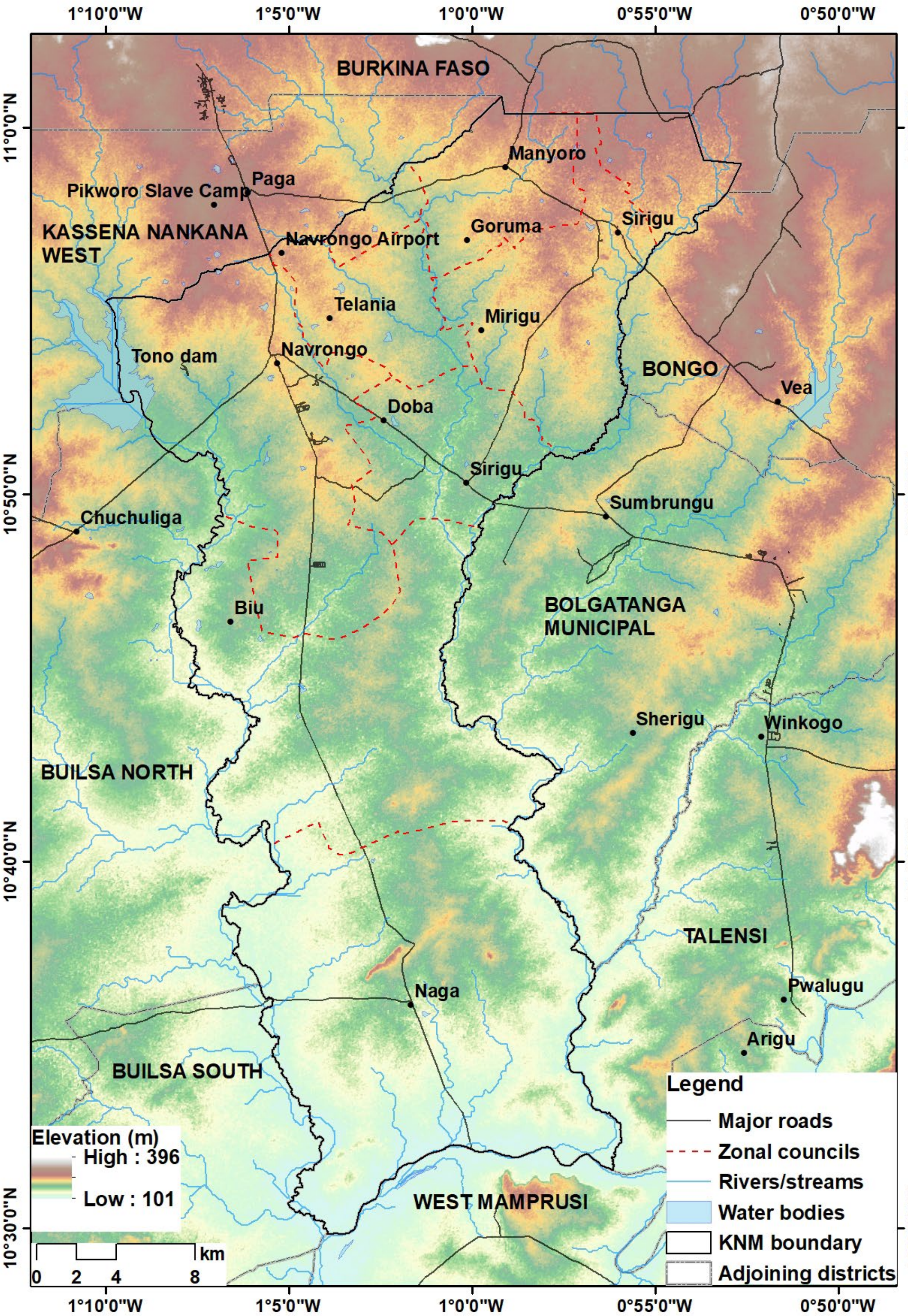
The local climate of the municipality is variable with wet/rainy and dry seasons influenced mainly by two air masses – the northeast trade winds and the tropical maritime southwesterlies. The rainy season begins in May and ends in October, while the dry season spans from November to April. Rainfall is highly variable spatially and temporally, a situation that has become more pronounced in the last decade. Other climate change manifestations that have been observed and reported in the literature include increasing changes in the incidence of floods, droughts, high intensity rainfall, and heavy winds.

2.5 Demographic Overview

The 2021 Population and Housing Census recorded the municipality's population at 99,895 people with a -0.89% annual population change from 2010 population (109,944) people. The population was 51.3% female and 48.7% male. An aging and maturing population presents opportunities and challenges to the municipality. The population density stood at 115.7 persons/km^2, which is lower than the regional average of 147 persons/km^2. An age dependency ratio of 1:0.84 implies that, on average each worker in the municipality cares for one or fewer dependents. Some rural communities in the municipality with populations of 1,000 persons and above include Abempengu, Akurugu Daboo, Biu, Bonia, Chaaba, Doba Kansa, Gomongo, Gongenia, Janania, Kologo Nayire, Korania, Manyoro, Naaga Choo, Natugnia, Nyangua, Nayagenia, Upper Gaane, and Vunania (Ghana Statistical Service, 2021).

The population of migrants in the municipality is about 16.25%, with 43.6% living there for less than 4 years and 26.4% for 20 years or more. The municipality has one of the largest irrigation schemes in the country, the Tono irrigation scheme, which is the main source of economic activities for smallholder farmers during the dry season. Consequently, there is a high influx of people into the municipality, albeit seasonal, especially among the relatives of Indigenous Kassenas and Nankanas living outside the municipality. The seasonal migrants come in search of land for cultivation or to provide labour for farmers.

Figure 4. Map of the Kassena Nankana Municipality showing physical and environmental features



Source: Author.

3. Vulnerability to Current Climate Change

This chapter details the district-specific methodology that was used to assess the vulnerability of KNM to climate change. It presents an overview of the manifestation of climate change and variability, i.e., patterns of rainfall, temperature, and extreme events; climate-sensitive sectors in the municipality; adaptation strategies being adopted; and data and research gaps to be addressed to enhance adaptive capacity and resilience of vulnerable populations. It further presents the stakeholder engagement approach used to select and develop data for the vulnerability indicators used in the assessment. A stakeholder workshop attended by representatives of eight stakeholder groups provided input on the perception of inhabitants on climate change impacts and feedback on pre-selected vulnerability indicators. The stakeholder engagement ensured acceptance and ownership of the methodology.

3.1 Stakeholder Engagement Plan

Eight stakeholder groups were engaged in assessing KNM's vulnerability to climate change. These were:

i. Government departments and agencies: Kassena Nankana Municipal, Ghana Meteorological Agency (GMA), Irrigation Company of Upper Region (COUR-Tono), Forestry Commission, Environmental Protection Agency (EPA), Ghana Irrigation Development Authority (GIDA), Ministry of Food and Agriculture (MOFA), National Disaster Management Organization (NADMO), and Ghana Education Service.

ii. Research and academia: Navrongo Health Research Center, C. K. Tedam University of Technology and Applied Science, and Bolgatanga Technical University.

iii. Private sector players: Water Users Association, Organization for Indigenous Initiatives and Sustainability, and Input Dealers Association.

iv. NGOs/CSOs: Center for Social Mobilization and Sustainable Development (CENSODEV); Institute of Social Research and Development (ISRAD); Research and Innovation for Sustainable Development (RISE); Link Community Development (LCD)

v. Vulnerable groups: Women in Agriculture Platform, youth groups, and Persons with Disability.

vi. Farmer groups: Tono farmer cooperative group, Rice Seed growers, and Peasant Farmers Association of Ghana.

vii. Media: Nabina and Pure FM.

viii. Traditional authorities from in and around the Kassena Nankana municipality.

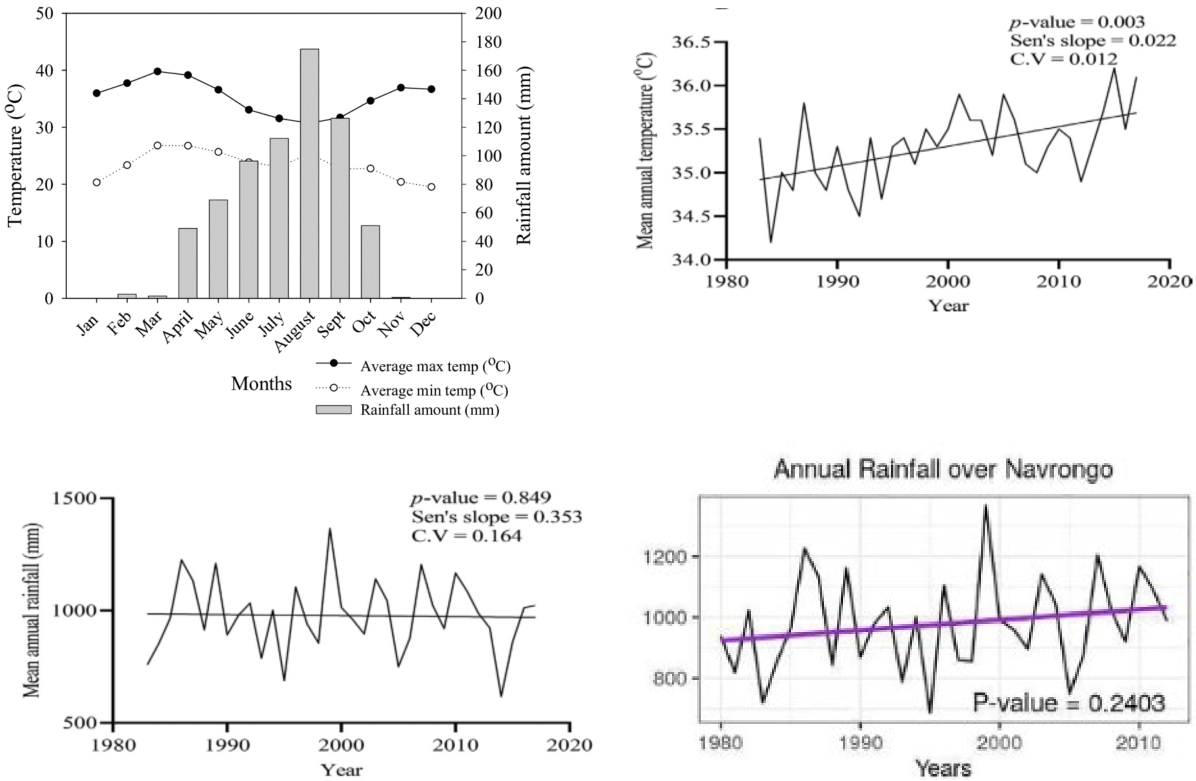
These stakeholders were engaged throughout the assessment period using multiple approaches such as key informant interviews, workshops, and surveys. The engagement was used to (i) collect information on climate change evidence, impacts, vulnerabilities, and adaptive strategies employed by vulnerable groups, (ii) discuss key aspects of the methodology, and (iii) collect data on indicators representing some or all three components of vulnerability assessment.

3.2 Climate Change Manifestation

Evidence of climate change and variability in the KNM was assessed based on a literature review and stakeholder engagement. Figure 5 illustrates the rainfall and temperature patterns in the Kassena Nankana Municipality. The Municipality has experienced highly variable rainfall since the 1980s, with an average annual rainfall ranging between 940 mm and 970 mm (Azongo et al. 2012; Incoom et al, 2020; Baffour-Ata et al. 2021), which peaks in August and declines thereafter. According to Amadou et al. (2015), the area exhibits an increasing trend in inter-annual variability but a non-significant decrease in the mean annual rainfall. Rainfall onset has progressively shifted from May to June over the past decade (Baffour-Ataa et al., 2021), while cessation has shifted backwards into the season, leading to a shortening of the rainy/cropping season and a prolonged dry season over the last 5 decades (Owusu et al. 2008; Nkrumah et al. 2014).

Temperatures have been consistently high and increasing (Yiran & Lindsay, 2016). Temperature has increased by almost a degree with an increasing trend over the last century and is projected to increase by 1.5°C to 3°C in the next 50 years (Klutse et al. 2020). Temperature in the Municipality and northern Ghana in general has been increasing at an annual rate of 0.02°C in the last 30 years (Stanturf et al. 2011), with monthly average temperatures ranging from 27.9°C to 32.6°C. National level studies such as Klutse et al. (2020) found the north-eastern part of the country, including the Municipality, to be one of the areas most affected by rising temperatures.

Figure 5. Rainfall and temperature patterns in the Kassena Nankana municipality



Source: MaCarthy et al., 2021; Baffour-Ata et al., 2021; Klutse et al., 2021.

Appendix 1 presents details of other studies conducted on the KNM with similar findings.

Discussions at the stakeholder engagement workshop confirmed the reality of climate change and variability as indicated by the studies reviewed above. Apart from shifts in the onset and cessation of rainfall, stakeholders complained about irregular distribution of rainfall during the cropping season. They unanimously confirmed the rising temperatures and alluded to its impact on water resources (high evaporation) and the health of residents in the municipality (e.g., Cerebro-Spinal Meningitis [CSM] outbreak).

Floods and droughts (including dry spells) are the two main extreme events experienced by the residents of KNM. In the case of droughts, NADMO and MoFA do not keep records of hydrological or agricultural droughts because of their limited monitoring capacity, which is insufficient to track droughts that are often thinly spread across the region (Incoom et al., 2020). However, information in the literature points to the susceptibility of the Municipality to droughts. For example, Incoom et al. (2020) found that apart from 1980s where most stations witnessed severe droughts, the Municipality witnessed the most intense drought in 2015, with an intensity of -2.45. Interviews with NADMO and MoFA officers as well as participants at the stakeholder workshop confirmed the increasing incidence of droughts and expressed worry at the limited options that are available to vulnerable populations in terms of overcoming this challenge. Workshop participants mentioned the need to improve the adaptive capacity of vulnerable populations to adopt water conservation technologies as a way of minimizing this impact, while appealing to government to make frantic efforts to increase irrigation infrastructure in the municipality.

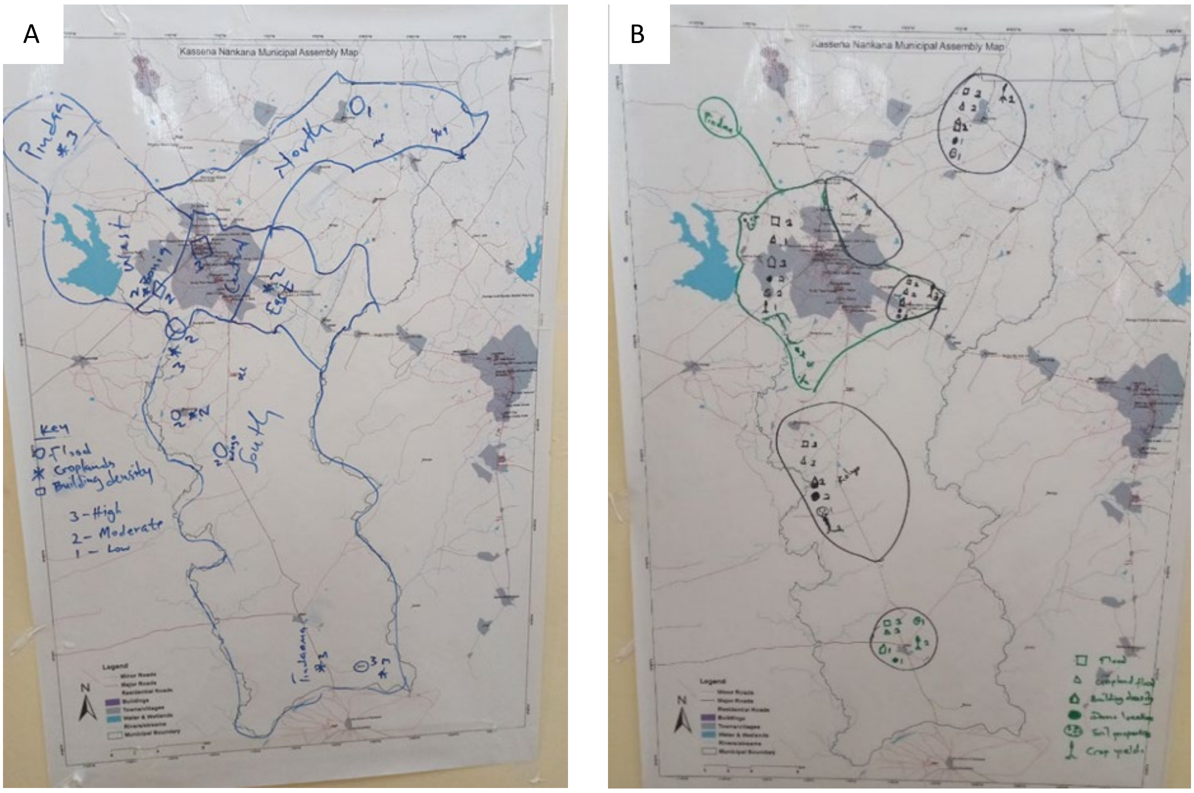
In the case of floods, the literature review indicated that there were more floods in the district than in the records given by NADMO and MoFA. The recent occurrences in 2019, 2021, and 2022 due to torrential rainfall and non-climatic factors (e.g., spillage of the Bagre dam) resulted in destruction of farmlands, livestock, and buildings, and 29 reported deaths for the Upper East region. Interviews and feedback at the stakeholder workshop indicated that communities such as Gumongo, Doba, Kandinga, Mirigu, and Naaga (see Figure 4) were frequently affected by floods due to their location in low lying areas and proximity to the White Volta (which receives spillage water from the Bagre Dam in neighbouring Burkina Faso).

Table 1. Sample list of disaster occurrences in the Kassena Nankana Municipality

Year	Occurrence	Climatic or non-climatic	Description of damage	Affected sector(s)	Number of affected people	Estimated cost	Source (e.g., literature, article, survey, etc.)
2021	Flood	Climatic	Some farms were submerged, i.e., about 30 ha of millet, maize and rice fields were affected. Communities affected include Kandiga, Gumongo, Merigu and Doba.	Agriculture	NA	NA	MOFA, Navrongo
2019	Flood	Climatic (torrential rainfall) and non-climatic (due to the spillage of the Bagre dam)	Farmlands and livestock were destroyed. 2000 buildings destroyed or severely damaged.	Agriculture Infrastructure (buildings)	29 reported deaths for the whole Upper East (no record for Kassena Nankana).	NA	MOFA and NADMO, Navrongo.
June 15, 2022	Rain Storm with high winds	Climatic	About 57 electric poles were pulled down, 87 houses had their roof completely or partially removed. A community clinic and JHS/Primary school also had their roofs taken off.	Services Infrastructure (buildings)			NADMO, Navrongo

Flood hazard zone maps were produced during the stakeholder workshop using a participatory approach. Figure 6a is divided into sub-municipal zones with the locations of hazards and their intensity indicated with symbols and numbers, respectively (see legend on left map). Figure 6b is divided into zones used by the Navrongo Health Research Center with the locations of hazards and affected infrastructure (e.g., buildings) indicated with symbols. In both maps, stakeholders were able to provide an indicative location of climate-induced hazards but could not indicate the spatial extent of the hazards.

Figure 6. Results of participatory hazard mapping



A: Map divided into sub-municipal zones with location of hazards and their intensity indicated with symbols and numbers, respectively (see legend on left map).

B: Map divided into zones of the Navrongo Health Research Center with location of hazards and affected infrastructure (e.g., buildings) indicated with symbols. In both maps, stakeholders were able to provide an indicative location of hazards but could not indicate the spatial extent of the hazards.

3.3 Climate Change Impacts and Vulnerabilities

3.3.1 Hazards and Associated Impacts on Sectors

Climate change has negatively impacted the key economic sectors in the Kassena Nankana Municipal Assembly. This section analyzes five sectors and provides an overview of each, describing the climate change impacts on the sector.

Agriculture

Overview

Agriculture is the most important sector in the KNM because the municipality's local economy is largely agrarian. The 2021 census revealed that 78% of the economically active population were employed by the agricultural sector. Agricultural activities include crop cultivation, livestock keeping, and fishing from natural and manmade lakes (GSS, 2021). Crop cultivation mainly takes place in the rainy season, during which farmers rely on rainfall. Cultivation in the dry season takes place close to water bodies using the Tono irrigation scheme and other small reservoirs and along major rivers such as the White Volta. Crops cultivated in the rainy season include maize, millet, rice, sorghum, and beans, while vegetables such as tomatoes, pepper, onions, and okra are mostly cultivated during the dry season. Farmers also maintain livestock throughout the municipality, usually in combination with crop cultivation using an integrated crop-livestock system. Farmers adopt such integrated approaches to derive co-benefits (e.g., livestock manure for crops or crop residue for livestock) and minimize risk. The main livestock raised are cattle, sheep, and goats, although others such as pigs, poultry, grasscutters (greater cane rats, *Thryonomys swinderianus*), rabbits, turkey, ducks, ostriches, silkworms, and doves are raised by some inhabitants to supplement household incomes and nutrition. About 4,905 people in the Kassena-Nankana municipality reared over 35,9052 animals for various purposes in 2010 (GSS, 2010). Fish farming is also an important income-generating activity in the municipality. This takes place in small reservoirs and large dams such as the Tono dam. Species that are cultivated include catfish and tilapia. Farmers sell most of their catch on the open market to generate income for their households.

Impacts

There are significant impacts of climate change on the sector through declining rainfall totals that in turn reduce crop yields, pasture for livestock, and food availability (Akudugu and Alhassan, 2012). Further, extreme events such as floods result in farms being submerged and livestock drowning, negatively impacting food availability and security. In addition to flooding, high temperatures and an increasing incidence of in-season droughts have been found to reduce crop yields (Apuri, et al. 2018; Antwi-Agyei et al. 2021). High temperatures also lead to high evaporation of water bodies, especially in the dry season when water is most needed for irrigation and livestock watering. Weather changes have increased the incidence of water-related pests and diseases such as coccidiosis and tsetse fly which cause sickness and death of livestock. Discussions with representatives of the municipal department of agriculture showed that torrential rains have caused many farmers to lose their field crops, livestock, and other valuable properties. A review of the period between 1983 and 2012 revealed that severe crop losses were recorded about 70% of the time torrential rains occurred, with greater impacts when droughts and floods occurred in the same year (Yiran and Stringer, 2016).

Human Health

Overview

Ghana's health sector is generally characterized by limited number of health facilities and inadequate health professionals, especially in rural areas. In the KNM in 2019, there were 25 health facilities comprising one hospital, 20 CHPS (Community Health and Planning Services) compounds, two health centres, one private clinic, and one CHAG clinic (Medium Term Plan, 2020). Emergency medical services help mitigate the limited reach of the health care system by providing essential medical care, basic pre-hospital assistance, and transport to health care facilities for injured individuals. However, compared to the World Health Organization's recommended doctor-to-patient ratio of 1:10,000 and nurse-to-patient ratio of 1:1000, the municipality has 1:65,297 and 1:1,419, respectively. This indicates a severe shortage of doctors in the municipality, which has implications for addressing climate-related diseases and epidemics.

Impacts

Stakeholders at the workshop attributed the increasing incidence of health epidemics in the municipality to increasing temperatures and extreme events such floods. Floods occasionally cause sanitation-related diseases such as cholera and diarrhea. For example, the destruction of sanitation facilities (at homes, schools, or health facilities) by floods often leads to cholera outbreaks in northern Ghana, with specific cases recorded in Kassena Nankana. But compared to flood-related diseases, stakeholders noted the increasing incidence of cerebrospinal meningitis (CSM), which is a climate-sensitive disease caused by high and extreme temperatures (Akanwake et al., 2022). Apart from CSM, high temperatures, especially in the dry season, also cause heat stress, which compels most community members to sleep outdoors (Ampadu, et al. 2018). Sleeping outdoors exposes vulnerable community members to insect-borne diseases such as malaria, as the insects that spread them are most active at night.

Energy

Overview

According to its Medium-Term Development Plan (2022-2025), the main sources of energy in the KNM are kerosene and gas lamps (51.4%); electricity (28.8%); flashlight and torch light (16.9%); others (0.9%); private generator (0.8%); firewood and crop residue (0.7%); candles (0.3%) and solar energy (0.4%). Principal sources of cooking fuel for households are fuel wood (59.2%), charcoal (18.7%), crop residue (10.2%), and gas (8.9%). The main source of electricity is hydropower (from Akosombo and Biu), although there exists a 2.5 MW solar grid in Navrongo, the Municipality's capital (KNM, 2021).

Impacts

Erratic rainfall patterns and temperature-induced evaporative losses are already impacting energy production from hydropower sources in Ghana. Although power generation takes place mostly south of Kassena Nankana, the municipality is impacted because its power supply comes from hydropower sources. In addition, temperatures increase energy demand through an increased need for refrigeration and air-conditioning. In this way, energy demand increases while production decreases. A reduction in energy production affects all socio-economic activities and human health and has a tendency to affect the capacity of the people to adopt alternative adaptation strategies (Fagariba et al., 2018; Ampadu et al., 2018; Apuri et al., 2018).

Water Resources

Overview

The municipality is drained by several rivers/streams and dams/reservoirs (see section 2.4 and Figure 4), which are important sources of water for domestic and other uses (e.g., agriculture). However, most small reservoirs and streams dry up during the dry season, constraining water availability and access. On household water supply, the Municipality has three small town water systems located at Biu, Pungu, and Kologo and 330 boreholes. These ensure that about 82% of the population have year-round sustainable access to safe water sources.

Impacts

The literature highlights high evaporative losses and sedimentation of reservoirs from high temperatures and high intensity rains (which cause runoff), respectively, as two of the most significant impacts of climate change on water resources in the Kassena Nankana municipality (Liebe et al. 2005). In particular, small reservoirs (dams) dry up in the peak of the dry season due to high evaporation. Reservoir storage volumes are also declining annually due to high sedimentation. Key informant interviews with officials at ICUOR and GIDA, as well as stakeholders at the training workshop, explained that low levels of water in small reservoirs due to climate change affect dry season cultivation. In addition, climate change and associated flooding also impacts water quality, which also has implications for human health (Azongo et al. 2012).

Forest and Biodiversity

Overview

There are five forests reserves in the municipality, all with an area of 164.09 km^2 and a perimeter of 95.6 km. The forests serve as water catchments areas; habitats for birds, bees, and other animals; and a source of timber, fuelwood, herbal medicine, and fodder for livestock. Among the dominant wildlife species found in the reserves are monkeys, reptiles, birds, and amphibians. The dominant plant species include baobab, nim, cassia, mahogany, teak, kapok, West African copal (daniella), eucalyptus, albizea and dalbergia. The forests are very economically important because of these many benefits and resources.

Impacts

Forestry officials in the municipality mentioned deforestation as one of the (indirect) impacts of climate change. Poor agricultural yields due to climate change impacts result in the expansion of cropland into forested areas as farmers compensate for low yields. Heavy winds uproot and destroy trees in the forest while changing rainfall and temperature patterns cause habitat loss and species extinction. High temperatures cause most of the trees to wither or dry up, creating an enabling environment for forest fires which destroy trees and kill wildlife. The cumulative effect of all these is that the tree population declines, and the forest is ultimately destroyed. Officials also mentioned the impact of rainfall and temperature changes as well as extreme events (e.g., floods) on forest soils and nutrients.

Infrastructure

Overview

Key infrastructure in the municipality includes transportation, buildings/housing, and information, communication and technology (ICT). On transportation, there are about four trunk roads (100 km in length), three secondary roads, and five feeder roads totaling about 327 km in the municipality. There is an airstrip in Paga (north of the municipality), although it is currently not in operation (MTDP, 2020). For buildings and housing, the main construction materials are mud, mud and cement, or cement only. Most houses in the rural areas of the municipality are constructed from mud and are highly vulnerable to floods and windstorms. The municipality is served by three telecommunications companies (Vodafone, Airtel-Tigo, and MTN), each having a mast and other infrastructure in the municipality or in neighbouring districts. The strength of the network signals is mostly high in towns and low in rural areas/communities.

Impacts

This sector is highly vulnerable to floods. As indicated in Table 1, previous flooding events have destroyed buildings and other infrastructure such as electricity poles. There have been reported incidents of road portions being washed away due to heavy rains, cutting off whole communities (GhanaWeb 2020). High temperatures also facilitate the deterioration of roads by causing cracks (Twerefou et al. 2018). With climate projections pointing to rising temperatures and increased incidence of high intensity rains and extreme events, these impacts are expected to worsen.

3.3.2 Sectoral Vulnerability to Climate Hazards

For the purposes of adaptation planning and action, it is important to rank climate change impacts on sectors to support prioritization of interventions in adaptation planning and action. Table 2 details the outcome of an exercise during the stakeholder workshop to rank each sector's vulnerability to the impacts of climate change. For each sector and category, stakeholders were given three options – high, moderate, and low to choose from. After deliberations, a determination of the rank was made based on a voice vote. The voice vote became necessary because different stakeholders (with different interests based on the sector under consideration) gave different rankings. Agriculture was ranked "high" in all the four categories of impact, followed by water resources, with the energy sector ranked as the least impacted because the municipality is not directly affected by climate change impacts on the sector (i.e., hydropower generation).

Table 2. Ranking of sector's vulnerability to impacts of climate change

Sector/ ranking	Certainty of impact	Timing of impact	Severity of impact	Importance of sector
Agriculture	**High:** Yields will be affected	**High:** Shifts in onset (planting time) and cessation (harvesting)	**High:** Low crop yields and changes in crop choices (shortening of season)	**High:** Major contributor to local economy and source of livelihoods for rural people
Water resources	**High:** Low water levels (drought) and flooding	**Moderate**: Low water levels for domestic use and irrigation during dry season	**High:** Dams/rivers drying up, hence no irrigation, affecting food security	**High:** Water is key to food production, energy generation, health, and sanitation
Human health	**High:** Flooding leading to poor sanitation and poor health conditions (e.g. malaria, diarrhea, dengue, CSM)	**Moderate:** Impact felt throughout the year: malaria, cholera, dengue during rainy season months and CSM during dry season months (peak months)	**High:** Impacts occur in poor sanitation areas and during the farming season	**High**: The health impact due to climate vulnerability is high during both the rainy and dry seasons, which affects productivity
Biodiversity	**High**	**Moderate**	**High**	**Moderate**
Energy	**Moderate:** Low rainfall results in low runoff into rivers and dams used for energy generation. Kassena Nankana is not directly impacted.	**Moderate:** Mostly during dry season when there are lower dam levels which affects energy generation.	**Moderate** The impact is not pronounced as many communities do not depend on the national energy grid. However, lower sunlight energy increases postharvest processes.	**Moderate**: The sector is important for food processing and alternative livelihoods.

3.3 Gender-Specific Impacts

Gender issues are critical in the face of changing climate in the KNM. Literature available has shown that climate change affects men, women, and vulnerable groups in different ways. Akrofi et al. (2018) asserted that climate change and variability are anticipated to disproportionately affect the well-being of the poor in the KNM and the Bongo district, such as female-headed households and people with limited access to land, advanced agricultural inputs, infrastructure, and education. According to Assan et al. (2020), women are marginalized in terms of accessing climate information and owning productive lands due to traditional land tenure systems. These factors often constrain women in decision making, a situation that limits their adaptive capacities to climate change impacts. Partey et al. (2020) revealed that male farmers are more likely to access climate information than their female counterparts. They attributed this to the gender roles women play and the relative ease with which men can access climate information using radios and mobile phones, driven by men's greater control of household income and financial resources. Consequently, climate-induced migration also tends to have a disproportionate impact on women and girls by compelling them to migrate south for other employment opportunities, such as taking the role of "Kayaye" (head porters). This business often makes them susceptible to sexual abuse by unscrupulous men.

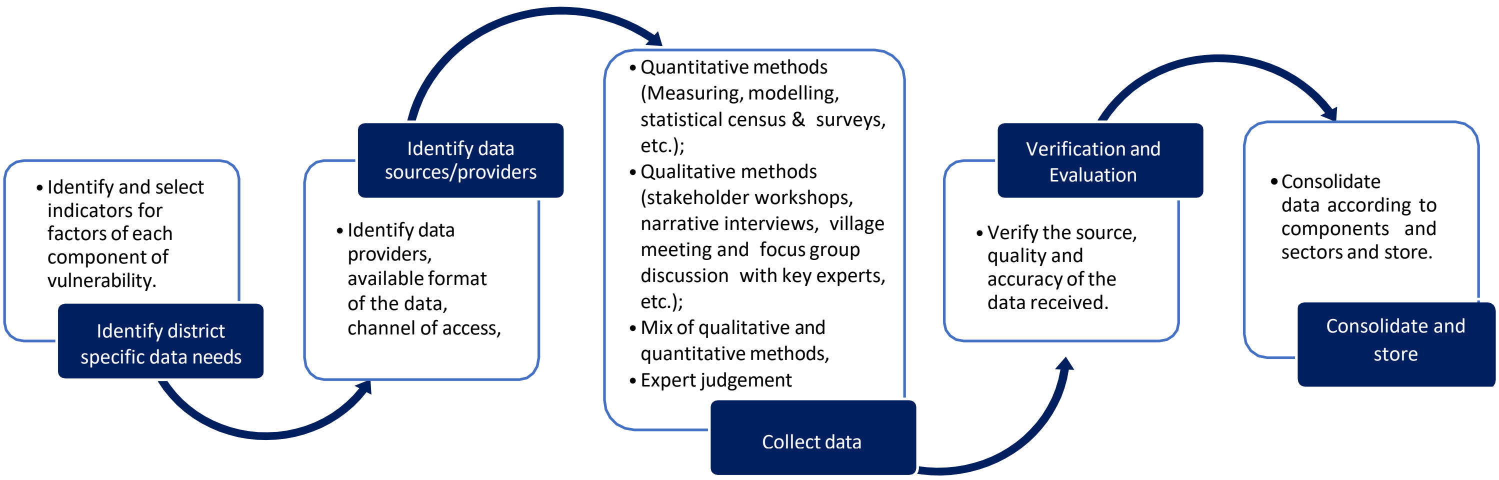
3.4 Knowledge and Data Gaps

Several studies have been conducted on the impact of climate change and variability on economic sectors of the Kassena-Nankana municipality. However, discussions during at the stakeholder workshop affirmed that there remain significant cross-cutting areas of knowledge and data gaps. In the case of adaptation strategies, many of the farmers employ local adaptation strategies to cope with climate change impacts. However, some of these strategies are increasingly failing. For example, farmers admit that prediction of the onset of the rains based on indigenous knowledge is not always effective. Knowledge and adoption of climate-smart technologies that achieve both adaptation and mitigation targets is limited. Additionally, the ability to quantify the extent of climate variability to implement the appropriate adaptation strategies remains a challenge, with inadequate knowledge on the months with extreme temperatures (see Issahaku et al. 2016; MacCarthy et al. 2021; Baffour-Ataa et al. 2021). Literature has shown that many of the extension officers do not have adequate knowledge and capacity to interpret climate data to support farmers, causing farmers to mostly rely on their perceptions and indigenous knowledge of climate change, which do not always hold true in times of change. Several studies have been done on climate change and its impacts on human health but there remains a research gap on the association of weather conditions with human health (see Azongo et al. 2012). Few studies have demonstrated the extent of the impacts of climate change on food security in the Kassena-Nankana municipality and the required appropriate adaptation measures (see Antwi-Agyei and Nyantakyi-Frimpong, 2021).

3.5 Vulnerability Assessment Methodology

The methodology adopted for assessing KNM's vulnerability to climate change follows the recommendation of the IPCC, which assesses vulnerability based on three key components: exposure, sensitivity, and adaptive capacity (see Chapter 1 for definitions). It entails the identification of indicators that represent each of the three components, data collection approaches for each indicator, data analysis using various analytical approaches, and final validation of the results. To ensure a successful process and ownership of the methodological approach and results of the assessment, stakeholder consultations and inclusion were pursued through a stakeholder workshop held to co-create the methodology. Pre-selected indicators were discussed by workshop participants and a final set of indicators were agreed upon by all stakeholders.

Figure 7. Methodological overview of Phase 2 of the vulnerability assessment



3.5.1 Vulnerability Indicators

Discussions on exposure elements indicated that communities in the KNM are highly exposed to climatic changes, with rainfall and temperature being the most prominent. Tables 3 and 4 give an overview of the set of indicators for sensitivity and adaptive capacity that emerged from discussions at the stakeholder workshop. Stakeholders confirmed the relevance of these indicators to their local context and suggested potential sources of data for each indicator.

Table 3. Sensitivity indicators for the vulnerability assessment

Indicator	Relevance to local context	Description (Feedback from brainstorming session)	Potential data source
Buildings in flood prone areas	Yes	Flooding of buildings experienced in isolated communities including Manyoro, Naaga, Biu, Korania and Kologo.	KNM planning unit and NADMO
Area of cropland in flood prone areas	Yes	Potential affected areas include Korania, Naaga, Bonia, Biu, Doba and Pidaa.	KNM planning unit and MOFA
Building density	Yes	Crowded areas include Zongo, Bonia, Navrongo township. The material used for building is extremely sensitive to high intensity rains and easily collapses. This is common in rural areas.	Land Use and Spatial Planning Authority (LUSPA) and GSS population census
Building material	Yes	Material with which buildings are constructed can influence someone's vulnerability to climate change, especially in the event of flooding.	Data source not readily known
Location of water bodies	Yes	A GIDA representative explained that dams are normally engineered followed by feasibility studies before construction, which could be an indicator of climate change. All dams irrespective of their location are affected by the following. • Reduced rainfall • Human activities • High temperatures • Forest cover.	Data source not readily known
Soil properties, e.g., soil organic carbon	No	This is not sensitivity indicator since most communities have adapted well to the soils.	NA
Crop area	No	Most crops cultivated are susceptible to the impact of climate change.	MOFA (Statistics, Research and Information Directorate) statistics

Adaptive Capacity

Table 4. Overview of stakeholder feedback on the relevance of pre-selected indicators for adaptive capacity for the vulnerability assessment

Factors	Relevance to local context	Description (Feedback from brainstorming session)	Potential data source
Indigenous seeds	Yes	Planting of drought and flood tolerant crops	MOFA, input dealers
Mobile cellular	Yes	Households/farmers require cellular phones to access services and other information	GSS
Agroforestry	Yes	Fruits trees such as shea, cashew, etc.	MOFA
Land-use planning and management	Yes	Farming and house practice	MOFA, LUSPA
Integrated crop and livestock systems	Yes	This reduces vulnerability of households in the sense that farmers can fall on one when the other fails	MOFA EPA
Income generating activities	Yes	On-farm and off-farm activities since there is only one raining season	MOFA
Early warning systems	Yes	Radio and telephoning to receive early warning information	GMET, Ghana Agricultural Sector Investment Programme, Farmerline
Dry season irrigation	Yes	Relevant for reducing climate-induced migration to southern Ghana	GIDA

3.5.2 Data Collection

The methodology for the quantitative vulnerability assessment included the following data collection methods:

1. Literature: Data for some indicators were gleaned from existing literature such as reports and scientific publications.
2. Surveys: Data for a significant number of indicators were acquired through key informant surveys, household surveys, focused group discussions, and workshops. Raw data collected through such surveys were analyzed to derive values for the desired indicator.
3. Geographic information systems and remote sensing data: This included data in existing geographic databases, satellite images, and gridded datasets. Datasets such as Digital Elevation Model (DEM), gridded precipitation and temperature data, gridded population or population density, optical satellite images (e.g., Landsat, Sentinel-2) and Synthetic Aperture Radar (SAR) data (e.g., Sentinel-1) all fall under this category. Like the survey data, these data were processed and analyzed to derive the desired indicator. For example, optical satellite imagery was classified to reveal cropland areas, which served as an input for the derivation of the indicator “area of cropland in flood prone areas.”

4. Model data: This included outputs/results from climate, hydrological, and crop models. The VA team used Global Circulation Models and Regional Climate Models that were not set up for the purpose of this assessment but provided relevant information.
5. Ground data and statistics: This included data from hydro-meteorological stations, including rainfall and temperature; and statistics from government agencies such as crop production or yield; and socio-economic variables, including employment and income.

Data for some of the indicators were derived from a single data source (e.g., access to electricity, which can be derived from household survey data). On the other hand, data for certain indicators were derived based on a combination of two or more of the five sources outlined above. For example, area of cropland in flood prone areas required the combination of cropland areas (e.g., from analysis of optical satellite data) and a map of flood-prone areas (e.g., derived from DEM using the Height Above Nearest Drainage [HAND] model).

3.5.3 Data Analysis

Qualitative and quantitative methodological approaches were applied to the collected data to get an overall picture of the municipality's vulnerability to climate change. The qualitative assessment focused on content analysis of key informant interviews, focus group discussions, literature reviewed, community surveys, and workshops conducted. The quantitative assessment combined quantitative estimates of the identified indicators to calculate a vulnerability index at a sub-municipal scale, i.e., at the level of zonal councils. Indicators of the three components (exposure, sensitivity, and adaptive capacity) were quantified, rescaled/standardized, and combined according to recommendations of the IPCC, a methodology that was also adopted in Ghana’s Fourth National Communication to the United Nations Framework on Climate Change (EPA, 2020). Chapter 4 provides more details of the methodology employed for the quantitative assessment.

The Vulnerability Index (see equation 1) ranges from -1 to +1, which signifies low and high vulnerability, respectively. A negative index indicates that the combined effects of exposure and sensitivity to climate change is less that the capacity of the impacted population to adapt to the changes. On the other hand, a positive index indicates that the adaptive capacity of the impacted population is lower than the combined effects of exposure and sensitivity. In this case, efforts are urgently needed to enhance the adaptive capacity of the population.

$$Vulnerability\ Index = (Exposure\ X\ Sensitivity) - Adaptive\ capacity \qquad (1)$$

4. Quantitative Vulnerability Assessment

The quantitative assessment entailed: (i) quantifying indicators related to the three vulnerability components through data collection and pre-processing, (ii) rescaling or standardizing values of indicators to between "0" and "1" where "0" represents no vulnerability and "1" represents high vulnerability, and (iii) combining rescaled indicators according to equation 1 and presenting results.

4.1 Quantifying Vulnerability Indicators

The quantification of indicators was achieved based on three main data sources: (i) observed/model data, (ii) household survey, and (ii) geographic information systems and remote sensing (GIS/RS). Table 5 lists the indicators for each vulnerability component, data source for its quantification, and references to the relevant sections that provides further details on the process of quantification.

Table 5. Data sources for quantifying vulnerability indicators

Component/Indicator	Data source	Details
Exposure		
Mean annual rainfall	Model data	CHIRPS[1]
Annual minimum temperature	Model data	ERA5[2]
Annual maximum temperature	Model data	ERA5
Sensitivity		
Building material	Household survey	Sampling & Questionnaire administration
Houses in flood prone areas	Household survey	Sampling & Questionnaire administration
Farms in flood prone areas	Household survey	Sampling & Questionnaire administration
Houses destroyed by floods	Household survey	Sampling & Questionnaire administration
Area prone to flooding	GIS/RS	Sampling & Questionnaire administration
Percent of cropland area in flood prone areas	GIS/RS	Digital Elevation Model/HAND (4.4.1)[3] Land use/land cover map (4.4.2)[4]
Percent of built-up area in flood prone areas	GIS/RS	Digital Elevation Model/HAND (4.4.1) Location of buildings (openstreetmap)[5]
Percent of population in flood prone areas	GIS/RS	Digital Elevation Model/HAND (4.4.1) Gridded population data (4.4.3)[6]
Adaptive Capacity		
Mobile phone ownership	Household survey	Sampling & Questionnaire administration
Access to internet	Household survey	Sampling & Questionnaire administration
Access to a market	Household survey	Sampling & Questionnaire administration
Access to a health facility	Household survey	Sampling & Questionnaire administration
Access to climate information services	Household survey	Sampling & Questionnaire administration
Access to climate tolerant seeds	Household survey	Sampling & Questionnaire administration

Component/Indicator	Data source	Details
Adoption of multiple adaptation strategies	Household survey	Sampling & Questionnaire administration
Practicing of crop/livestock systems	Household survey	Sampling & Questionnaire administration
Access to water for dry season irrigation	Household survey	Sampling & Questionnaire administration
Knowledge of agricultural insurance	Household survey	Sampling & Questionnaire administration

Notes:

[1] Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data is a 35+ year quasit-global rainfall dataset.

[2] ERA5 - The fifth generation atmospheric analysis of global climate covers the period from 1940 to present.

[3] Digital Elevation Model (DEM)/Height Above Nearest Drain (HAND) (4.4.1) - A one arc-second (ca. 30 m resolution) DEM from the Shuttle Radar Topography Mission was downloaded from the Earth Explorer portal of the United States Geological Survey.

[4] Land use/land cover map - WorldCover 2020 LULC map generated by the European Space Agency.

[5] Location of buildings – openstreetmap, a free database that provides the geographical location of buildings.

[6] Gridded population data – 100-meter resolution gridded population data for the municipality downloaded from Worldpop.

4.1.1 Model Data

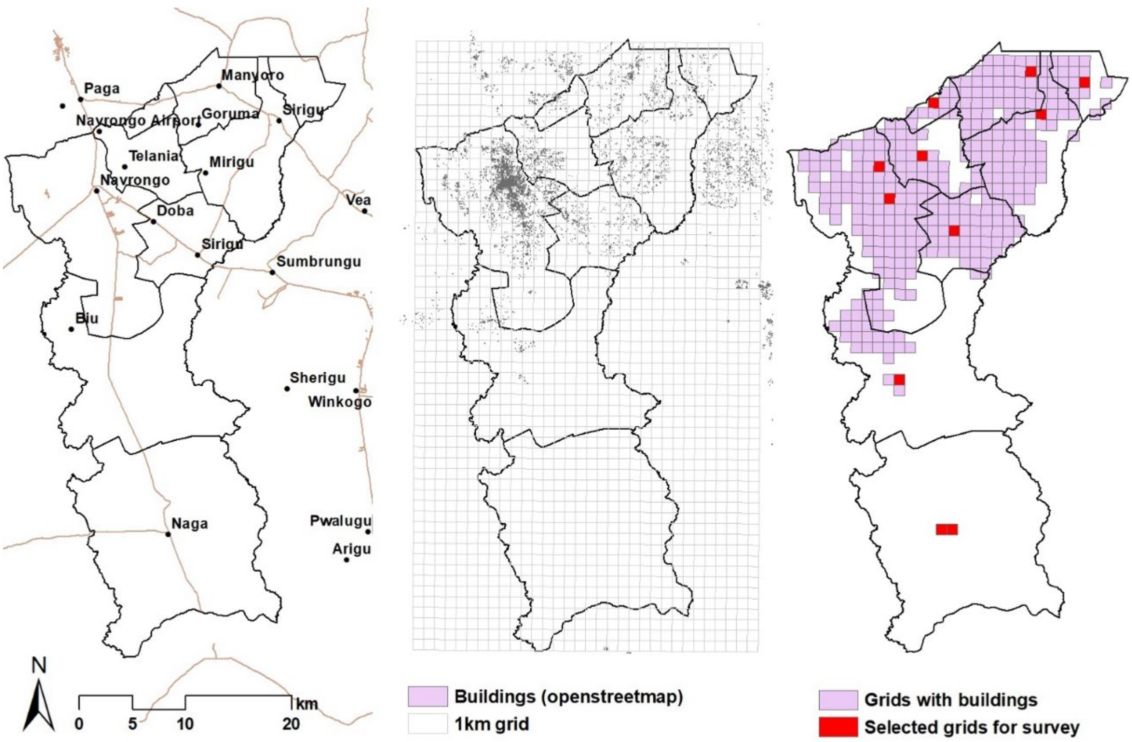
The exposure indicators were quantified based on observed climate data from the Ghana Meteorological Agency and model data from satellite observations. The specific climate variables analyzed are rainfall and temperature. The source of model data used for the rainfall-related indicators was the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data while ERA5 data were used for the temperature-related indicators. The data used, which are mainly historical, spanned from 1980 to 2020. Data cleaning and quality control were performed to avoid any non-climatic factors influencing the analysis. The Climdex package in R statistical software was used for quality control checks. The observed data served as input.

4.1.2 Household Survey

The household survey was conducted to generate data for the indicators representing all three vulnerability components – exposure, sensitivity, and adaptive capacity. However, the questions focused more on indicators of adaptive capacity because other components benefitted from other data sources such as models and GIS/RS. A questionnaire was developed to elicit responses that enabled the quantification of the indicators. The questionnaire was originally intended to be administered directly via Google forms, but due to internet connectivity challenges, hardcopy versions were printed and administered where connectivity was a challenge. Hardcopy-administered questionnaires were subsequently entered into the database of responses via Google forms.
The questionnaire can be viewed in Appendix 2.

The design of the household survey and sampling followed the approach proposed by Wagenaar et al. (2018). Sampling and the subsequent survey were conducted at the zonal council level. Households were sampled from each of the nine zonal councils in the KNM. To determine the optimal areas for sampling, the geographical locations of buildings were taken from OpenStreetMap and processed in a GIS environment. As buildings represent the location of households, this layer served as the basis for determining priority locations for sampling. The locations of schools, hospitals, markets, and other facilities were also obtained via OpenStreetMap. A 1-km grid was generated in a GIS environment and overlaid on the buildings layer. This overlay enabled the calculation of the building density across the municipality, in units of buildings per one-square-kilometer grid. Based on the computed building density layer, at least one grid was selected per zonal council to be the focus of household surveys. Grids were selected using the probability proportional to size sampling frame, which was executed using the “pps.sampling” function in the “Samplingbook” package in R Statistical and programming Software (R Core Team, 2021). Figure 8 shows the building density and the selected grids. For each of the selected grids, enumerators navigated to the centre of the grid and randomly selected at least 20 households to administer the survey questionnaire. A total of 225 questionnaires were eventually administered and subsequently analyzed to derive quantities for vulnerability indicators of interest. The survey was conducted using Google forms (where enumerators had internet access) or with a hardcopy of the questionnaire printed prior to the survey. The survey responses were processed mostly as percentages, i.e., the percentage of respondents that selected a particular option.

Figure 8. Gridding and sampling grids for household survey



Left: Map of zonal councils and major roads.

Middle: Location of buildings from OpenStreetMap overlaid with a 1-km2 grid.

Right: Location of sampled grids for questionnaire administration.

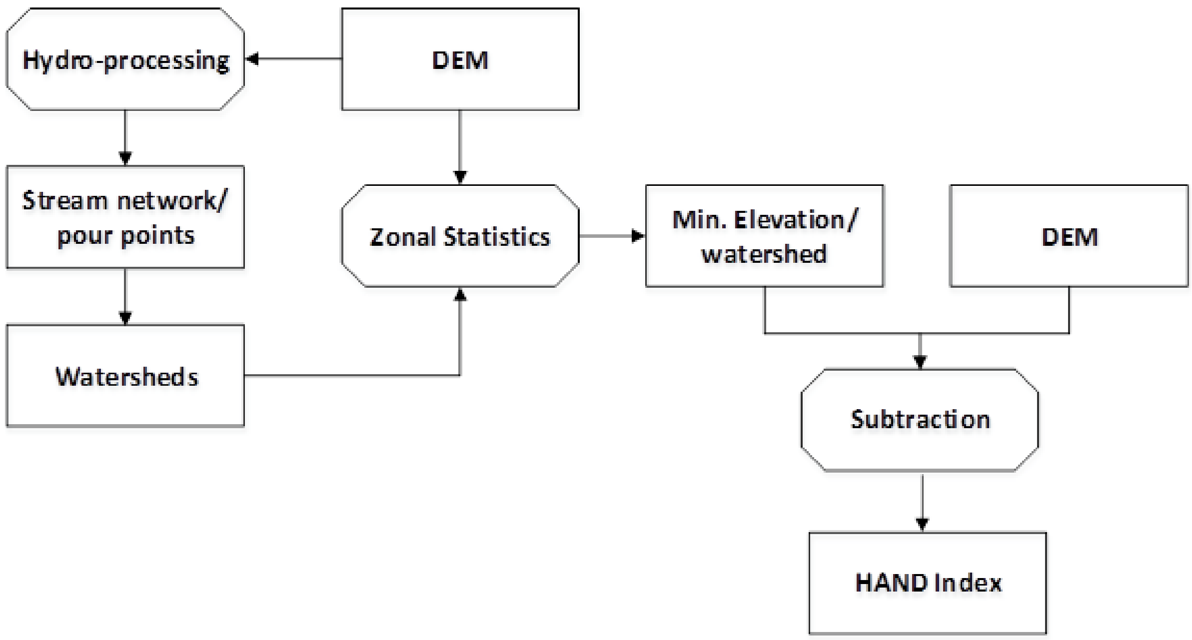
4.1.3 GIS/RS

Digital Elevation Model

A Digital Elevation Model (DEM) was used to delineate flood hazard zones in the KNM based on the Height Above Nearest Drainage (HAND) model. A one arc-second (ca. 30 m resolution) DEM from the Shuttle Radar Topography Mission (SRTM) (Farr and Kobrick, 2000) was downloaded from the Earth Explorer portal of the United States Geological Survey. SRTM data have been used in several flood mapping studies and has been found to accurately represent different landscapes due to its high spatial resolution and vertical accuracy (Kwak et al., 2012; Samela et al., 2015). Elevation and its derivatives (e.g., slope) are a good indicator of flood susceptibility and hence a useful parameter to be considered in flood hazard and risk mapping (Bapalu and Sinha, 2005; Todini et al., 2004). A description of the HAND model and processing steps to derive it from a DEM is provided below.

HAND Model: The Height Above Nearest Drainage (HAND) model was used to delineate flood hazard zones in the Kassena Nankana municipality. HAND is a hydrological landscape classification procedure developed by Royal HaskoningDHV (Rennó et al., 2008). The model utilizes the height above the nearest drainage river network and the surface slope, which can be easily obtained from a DEM. The model has been successfully applied at varying spatial scales to estimate potential hazard zones. A global application of the method can be found in Donchyts et al. (2016). The model produces an index that can be categorized into different flood hazard levels. Figure 9 demonstrates the approach used in calculating the index.

Figure 9. Graphical overview of the process for deriving height above nearest drainage (HAND) from a DEM



Source: Author.

Below is a summary of the steps undertaken to calculate the HAND index per basin:

a) A depressionless DEM was calculated by removing all sinks (holes) from the DEM to ensure that water flows from one grid cell to the other.

b) A flow direction map was computed from the depressionless DEM in a GIS environment. This algorithm determines the direction in which water will flow on a surface. It outputs a result that indicates eight possible flow directions.

c) Based on the flow direction grid, a flow accumulation grid was computed. The result depicts the total amount of water that flows assuming a unit (e.g., 1 mm) of rainfall on each elevation grid cell.

d) A stream network was subsequently derived from the flow accumulation grid by specifying a threshold value that defines a drainage/stream channel. The threshold specified determines the density of the resultant drainage network. In this study, the mean value of the flow accumulation grid served as a guide in determining the threshold.

e) Next, a watershed layer was derived based on the flow direction grid and the location of possible outlet(s) on each extracted drainage channel. This procedure determines the contributing area for each defined outlet (or pour point).

f) The minimum elevation in each watershed was determined by running a zonal statistics algorithm in a GIS environment. The inputs to this are the watershed layer computed in (e) above and the DEM.

g) The HAND index was determined by subtracting the layer of minimum elevation per watershed from the DEM. Thus, for each drainage area (watershed), the HAND is calculated as the difference between the elevation (per pixel) and minimum elevation as determined in (f) above.

The result of the HAND model enabled the calculation of the percentage of zonal council area that is prone to flooding as well as farmlands, populations, and households that are in flood prone areas.

Land Use/Land Cover

A land use/land cover map was used to determine the location and extent of certain land use and land cover (LULC) types of interest – cropland, water bodies, built-up areas or settlements. The 10 m resolution WorldCover 2020 LULC map generated by the European Space Agency was downloaded and processed for use in this analysis (European Space Agency, 2020). The map contains eleven generic LULC classes: tree cover; shrubland; grassland; cropland; built-up; bare/sparse vegetation; snow and ice; permanent water bodies; herbaceous wetland; mangrove; and moss and lichen. An independent validation of the LULC map by the Wageningen University (statistical accuracy) and International Institute for Applied Systems Analysis (IIASA) (spatial accuracy) revealed an overall accuracy of 74.4%. Coupled with the flood hazard zones delineated in section 4.4.1 via the HAND model, analyses were conducted to determine the percentage of cropland, and built-up areas/settlements that fall in prone areas per zonal council.

Population

Gridded population data were used to determine the number of people susceptible to flood hazard in each zonal council. A 100-metre resolution gridded population dataset from Worldpop (2023) was downloaded for the Municipality. One advantage of this dataset is that it has been adjusted to the United Nation's population projection estimates. An overview of the data can be found in Tatem (2017), while details of the modeling methods are explained in Stevens et al. (2015). Data for the year 2020 were downloaded. Together with the flood-prone areas delineated via the HAND model, the number of people who live in prone areas in each zonal council was determined.

4.2 Rescaling of Indicators

The scale/unit of the sensitivity and adaptive capacity indicators were percentages, with a value range between "0" and "100." However, the units of the exposure elements were millimeters and degrees Celsius. Therefore, different approaches were adopted to rescale these values linearly to between "0" and "1," where "0" represents no/low vulnerability to climate change and "1" represents high vulnerability. Two rescaling methodologies were applied to two distinct cases as indicated below:

i. For indicators that had units in percentages, equation 2 was applied:

$$X_r = X_i/100 \qquad (2)$$

ii. For indicators that units as millimeters and degree Celsius, equation 3 was applied:

$$X_r = (X_i - X_{min})/(X_{max} - X_{\mathrm{min}}) \qquad (3)$$

where X_r is the rescaled value, X_i is the original value, X_{min} and X_{max} are the minimum and maximum values respectively.

Table 6. Summary of the indicators (per vulnerability component), the original value range, rescaling approach and equation applied (in brackets), and the range of rescaled values

Indicator	Value range	Interpretation	Rescaling approach	Rescaled values[1]
Exposure				
Mean annual rainfall	[mm]	High annual rainfall signifies high vulnerability	Linear (3)	[0 – 1]
Annual minimum temperature	[deg. Cel]	High temperature signifies high vulnerability	Linear (3)	[0 – 1]
Annual maximum temperature	[deg. Cel]	High temperature signifies high vulnerability	Linear (3)	[0 – 1]

Indicator	Value range	Interpretation	Rescaling approach	Rescaled values[1]
Sensitivity				
Building material	[0 – 100]	High percentage of people with mud houses signifies high vulnerability	Linear (2)	[0 – 1]
Houses in flood prone area	[0 – 100]	High percentage of houses in flood-prone areas signifies high vulnerability	Linear (2)	[0 – 1]
Farms in flood prone areas	[0 – 100]	High percentage of farms in flood-prone areas signifies high vulnerability	Linear (2)	[0 – 1]
Houses destroyed by floods	[0 – 100]	High percentage signifies high vulnerability	Linear (2)	[0 – 1]
Flood hazard area in zonal council	[0 – 100]	High percentage of flood hazard area in council signifies high vulnerability	Linear (2)	[0 – 1]
Percent of cropland area in flood hazard zones in council	[0 – 100]	High percentage signifies high vulnerability	Linear (2)	[0 – 1]
Percent of built-up area in flood hazard zones in council	[0 – 100]	High percentage signifies high vulnerability	Linear (2)	[0 – 1]
Percent of population in flood hazard zones	[0 – 100]	High percentage signifies high vulnerability	Linear (2)	[0 – 1]
Adaptive capacity				
Percent of people with mobile phones	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with internet access	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with access to market in less than 30 min	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with access to hospital in < 30 min	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with access to climate information services	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with access to climate tolerant seeds	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people using multiple adaptation strategies	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people practicing crop / livestock system	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with access to water for dry season agric.	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people with knowledge of agricultural insurance	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]
Percent of people who have subscribed to agric. insurance	[0 – 100]	High percentage signifies low vulnerability	Linear (2)	[0 – 1]

4.3 Results

Summary results of the household survey are presented in section 4.3.1. Results are summarized by zonal council in terms of demography, socio-economic, climate change impacts, sensitivity, and adaptive capacity. Comparisons are between two or more zonal councils to highly intra-municipal variations or differences. Appendix 3 provides the detailed responses received from the questionnaire administration.

4.3.1 Vulnerabilities Across Zonal Councils

Responses from the household survey were analyzed qualitatively (content analysis) and quantitatively (percentages) to understand intra-municipal differences in vulnerability to climate change. Analyses were conducted at the zonal council level. The following paragraphs provide an overview of the situation in each zonal council.

Biu Zonal Council

The sampled population in the Biu zonal council of the Kassena Nankana Municipal Assembly was made up of 86.7% men and 13.3% women, most of whom were farmers (80.0%), with 20% being unemployed. Sixty percent were older than 40 years, and more than half (53.3%) have received formal education. Farming is mainly rain-fed, with limited or no farming activities during the dry season. Eighty-six percent of respondents indicated not having access to water for dry season cultivation.

A shift in the onset and cessation of rainfall as well as an increase in the incidence of drought during the cropping season were mentioned by more than half (53.3%) of the respondents as climate change impacts being experienced. A significant percentage (80%) indicated that the zonal council has experienced an increasing incidence of high intensity rainfall, high temperatures, and floods in recent years. This confirms their high level of exposure to climate change.

Close to half (46.7%) of respondents have their houses constructed with mud/bricks, while 33.3% have mud/bricks and cement as the building materials of their houses. This makes most buildings in the zonal council susceptible to flooding. Unsurprisingly, 93% of respondents revealed that either their homes, farms, or livestock pens have been damaged by floods before. Internet is available in the neighbourhood, but accessibility is challenging because only about a quarter (26.7%) of the inhabitants own a smartphone, with 66.7% having “Yam” phones (mobile phones with limited functionality that typically only make calls and send texts). About 73% of respondents indicated not having access to the internet, while 26.7% occasionally have access. In addition, the network is unreliable, and most respondents indicated not having enough money to purchase data to access the internet. This has implications on access to certain services that may require access to the internet (e.g., Climate Information Services [CIS]).

The survey revealed that inhabitants of the zonal council have access to inputs and services that increase their resilience to climatic changes. For example, 60 percent have access to climate information services, while all respondents indicated having access to climate-tolerant seeds. Concerning the adoption of adaptation practices (e.g., agroforestry, conservation agriculture, etc.), about three-quarters (73.3%) revealed adopting multiple practices to reduce climate change impacts and increase resilience. Relatedly, 80% were found to practice crop/livestock systems compared to

20% for crops only (no respondent kept only livestock). About 53.3% of the respondents were also involved in other alternative livelihoods (e.g., trading, migration) as an adaptation strategy. These allude to the effort of inhabitants of this zonal council to adopt practices that increase their resilience to climate change. However, knowledge of agricultural insurance was found to be poor, with about half of respondents (53.3%) having no knowledge, while 86.7% indicated not subscribing to an agricultural insurance scheme. Increased sensitization is, thus, needed to enable farmers to appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Doba Zonal Council

The Doba zonal council's sampled population was made up of 82.4% men and 17.6% women. About two-thirds (64.7%) of the population were farmers, while the remainder were either jobless or involved in other economic activities (e.g., civil service, business, etc.). Seventy percent were over 40 years old, and formal education is high (76.5%) relative to Biu (53.3%). Farming is primarily rain-fed and there are minimal farming operations during the dry season. Fifty-two percent of respondents said they had no access to water, while 47.1% said they occasionally or annually had access to water for dry-season farming.

All respondents indicated that the zonal council has been experiencing an increasing incidence of floods and high temperatures in recent years. Climate change impacts such as a shift in the onset and cessation of rainfall, as well as an increase in the incidence of high intensity rainfall and drought during the cropping season, were reported by more than 76% of respondents. This confirms their level of exposure to climate change, as 23.5% and 47.1% respondents, respectively, showed high and very high exposure to climatic changes.

The houses of most respondents (76.5%) were built with mud/bricks, whereas for 11.8%, mud/bricks and cement were used. Consequently, most buildings in the zonal council are vulnerable to floods. Unsurprisingly, 76% of respondents said that floods had previously damaged their homes, farms, or animal pens. Even though nearly half (47.1%) of the residents own a smartphone, with 41.2% using "Yam" phones, access to the internet remains a challenge. Approximately 76.5% of respondents said they had no access to the internet, while 11.8% said they have occasional access. The network is also inconsistent, and most respondents said they lacked the funds to buy data to access the internet. This has implications for residents' access to certain services that may require access to the internet (e.g., CIS).

According to the survey, people living in the Doba zonal council have limited access to some services that improve their ability to withstand climate change. Only a small percentage of respondents (17.6%) said they always have access to seeds that can withstand the changing climate, despite 58% of the respondents receiving climate information services through radio. A substantial portion (94.1%) of those who reported adopting varied adaptation measures (such as agroforestry, conservation agriculture, etc.) did so to mitigate the effects of climate change and boost resilience. Additionally, 94.1% were found to use crop/livestock systems compared to 5.9% for crops only (no respondent kept only livestock). As a coping mechanism, around 70% of the respondents also engaged in other non-traditional economic activities including trade or migrating. This suggests that effort is put forth by the locals in this zonal council to adopt behaviours that improve their adaptability to climate change. However, it was discovered that less than half (47.1%) of respondents had any knowledge of agricultural insurance, and 70.6% said they did not participate in any agricultural insurance programs. Therefore, greater awareness is required to enable farmers to understand how agricultural insurance can further improve their adaptation to climatic changes.

Manyoro Zonal Council

The sampled population in the Manyoro zonal council comprised 63.4% men and 36.8% women. In terms of occupation, 52.6% are farmers, 15.8% are unemployed and 31.6% are engaged in other activities (e.g. civil service, business etc.). Sixty-eight percent are older than 40 years, and a significant percentage (73.7%) have received formal education. Similar to other zonal councils, farming is mainly rain-fed due to limited availability of water in the dry season. However, compared to Doba and Biu, a higher percentage (42%) of respondents in this zone indicated having access to water in the dry season for cultivation.

A shift in the onset and cessation of rainfall, high temperatures, and an increase in the incidence of drought during the cropping season were mentioned by about 80% of the respondents as climate change impacts they experienced. However, only 36.8% indicated that the zonal council has been experiencing an increasing incidence of high intensity rainfall and floods in recent years. Fifty-seven percent of the respondents indicated that they are highly exposed to climate change.

Compared to Biu (46.7%) and Doba (76.5%), the percentage of houses constructed with mud/bricks are significantly lower (15.8%) while those made from mud/bricks and cement and cement alone, respectively, are 52.6% and 31.6%. This makes buildings in the zonal council less susceptible to flooding. Consequently, only 36% of respondents revealed that either their homes, farms, or livestock pens have been damaged by floods before. Although there is internet availability and more than half (57.9%) of respondents indicated owning smartphones, accessibility is still a challenge. The network is unreliable, and most respondents indicated not having enough money to purchase data to access the internet. This could limit access to certain services that may require internet connectivity (e.g., CIS).

The survey further revealed that inhabitants of the zonal council have limited access to inputs and services that increase their resilience to climatic changes. For example, only 42% have access to climate information services from different sources (e.g., radio station, community radio, etc.,), while a vast majority (89.5%) of respondents indicated not having access to climate-tolerant seeds. Concerning the adoption of adaptation practices (e.g., agroforestry, conservation agriculture, etc.), about 68% and 32.0% revealed adopting multiple practices and organic fertility, respectively, to reduce climate change impacts and increase resilience. Relatedly, 78.9% were found to practice crop/livestock systems compared to 15.8% practice of crops only (inter-cropping) and 5.3% of livestock only. About 47.4% of the respondents, who are farmers, were also involved in alternative livelihoods (e.g., trading, formal employment, migration) as an adaptation strategy. These demonstrate the effort of inhabitants of this zonal council to adopt practices that increase their resilience to climate change. However, as in other zones, knowledge of agricultural insurance was found to be poor, with more than half of respondents (57.9%) having no knowledge, while all of them indicated not subscribing to an agricultural insurance scheme. Increased sensitization is, thus, needed to enable farmers appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Naaga Zonal Council

The Naaga zonal council survey participants were comprised of 61.9% men and 38.1% women, with most of the population working as farmers (90.5%), and the remaining either unemployed (4.8%) or engaged in other occupations such as business (4.8%). This zonal council has a relatively younger population, with over 57% of respondents aged 40 years or over, compared to 68% and 70% for Manyoro and Doba, respectively. Farming is primarily rain-fed, with little to no activity taking place during the dry season. For dry season farming, 95% of respondents said they lacked access to water for irrigation during that period.

More than 80% of the respondent indicated that the zonal council has been experiencing high temperatures, an increasing incidence of high intensity rainfall, and floods in recent years. A shift in the onset and cessation of rainfall as well as an increase in the incidence of drought during the cropping season were mentioned by more than 60% of the respondents as climate change impacts being experienced.

Houses constructed with mud/bricks, mud/bricks and cement, and cement only represent 38.1%, 52.4%, and 9.5%, respectively. Sixty-one percent of respondents revealed that their homes, farms, or livestock pens have been damaged by floods before. Despite internet availability in most areas, 80.5% of respondents either have no phones or own phones ("Yam phones") that are not suitable for accessing the internet. Consequently, 85.7% of respondents mentioned not having access to internet, while just about 14.3% have it. Apart from fewer people owning internet complaint phones, respondents mentioned unreliability of the network and most respondents indicated not having enough money to purchase internet bundles. Inhabitants, thus, often miss out on services that may require internet connectivity such as CIS.

The survey revealed that inhabitants of the zonal council have limited access to inputs and services that increase their resilience to climatic changes. For example, 71% have no access to climate information services, and 76% of respondents indicated not having access to climate-tolerant seeds. Concerning the adoption of adaptation practices (e.g., agroforestry, conservation agriculture, etc.), 81.0% and 14.3% of the respondents revealed adopting multiple practices and the use of organic fertilizer, respectively, to reduce climate change impacts and increase resilience. All the respondents (100%) were found to practice crop/livestock systems (no respondent kept only livestock or crops), which reduced their risk of either crop failure or mass livestock mortality. Knowledge of agricultural insurance was found to be poor in this zone as well, with about half of respondents (57.1%) having no knowledge, while 71.4% indicated not subscribing to an agricultural insurance scheme. Increased sensitization is, thus, needed to enable farmers to appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Navrongo Zonal Council

The male-female ratio of the sampled population in the Navrongo zonal council was more even (59.3% versus 40.7%) than found in other zones. Unlike other zones where most inhabitants are farmers, more than half of respondents in this zonal council are engaged in non-farming activities (55.6%), while 37.0% are farmers. Fifty-five percent are older than 40 years, and about 92% have received formal education. Seventy-four percent of respondents indicated not having access to water for dry season cultivation.

All the respondents (100%) indicated that the zonal council has been experiencing high temperatures, as well as a shift in the onset and cessation of rainfall in recent years. Drought was indicated as a challenge, as 85.2% of respondents reported an increase in the incidence of drought during the cropping season, 70.4% on high intensity rainfall, and 51.9% on flooding. Forty percent and 30% of respondents, respectively, indicated having a very high and high exposure to climate change.

The percentage of respondents whose houses were built with mud/bricks, mud/bricks and cement, and cement only are 11.1%, 55.6% and 33%, respectively. The low percentage of buildings constructed with mud/bricks can be attributed to the urban nature of the zonal council. Consequently, buildings in the zone are expected to be less susceptible to flooding. However, 70% of respondents revealed that their homes, farms, or livestock pens have been damaged by floods before. This can be attributed to the intensity of rainfall and limited or blocked drainage channels. Internet is available in the neighbourhood, but accessibility is limited to about 51.9% of the inhabitants who own smartphones. About 37% of respondents indicated not having access to the internet because their phones (i.e., “Yam phones”) are not suitable for accessing the internet. Network unreliability was mentioned as a challenge in this zone as well, while respondents mentioned limited financial capacity to purchase data to access the internet. Therefore, access to certain services that may require internet connectivity such as CIS could be limiting for inhabitants of this zonal council.

The survey revealed that respondents have limited access to inputs and services that increase their resilience to climatic changes. Forty-four percent indicated having access to climate information services, while 77.8% mentioned not having access to climate-tolerant seeds. About 48% revealed adopting multiple adaptation practices such as agroforestry, conservation agriculture, etc., and similarly, 85.2% were found to practice crop/livestock systems compared to 14.8% for crops only (intercropping and mono-cropping), while no respondent practiced only livestock systems. Another adaptation strategy noted was the adoption of alternative livelihood options, with 63% of the respondents involved in activities such as trading, temporary migration to the south, etc. About 70% of respondents indicated not having knowledge of agricultural insurance, with about 70.4% of respondents having no knowledge, while 88.9% indicated not subscribing to an agricultural insurance scheme. Increased sensitization is, therefore, needed to enable farmers to appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Yua Zonal Council

The sampled population in this zonal council comprises of 66.7% men and 33.3% women, most of whom are farmers (79.2%), and an unemployed population of 20.8%. The sample reflected a relatively youthful population, with only 45% being older than 40 years. About two-thirds of respondents (63%) have received formal education. Ninety-five percent indicated not having access to water for dry season cultivation, which makes agriculture predominantly rainfed in the zonal council.

A significant percentage (> 90%) indicated that the zonal council has been experiencing high temperatures, an increasing incidence of drought during the cropping season, and floods in recent years. A shift in the onset and cessation of rainfall as well as an increase in the incidence of high intensity rainfall were mentioned by more than 67% as climate change impacts being experienced. Twenty percent, 33.3%, and 29.2% respondents rated the council’s level of exposure to climate change very high, high, and moderate, respectively.

More than 87.5% of respondents have their houses constructed with mud/bricks, 8.3% with mud/bricks and cement, and 4.2% with only cement as the building materials of their houses. This makes buildings in the zonal council highly susceptible to flooding. About 54.2% of respondents revealed that their homes, farms, or livestock pens have been damaged by floods before. The internet is available in the neighbourhood, but approximately 62.5% of respondents said they did not have access, 8.3% said they have, while 29.2% said they have access but only occasionally. Reasons for the limited access to the internet include fewer people (29.2%) owing phones that are suitable for accessing internet, unreliable network, and limited financial capacity to purchase data to access the internet. This situation could limit inhabitants' access to services that require access to the internet (e.g., CIS).

The survey revealed that inhabitants of Yua have limited access to inputs and services that increase their resilience to climatic changes such as access to climate information services (45%) and access to climate-tolerant seeds (24.5%). Ninety-five percent of respondents revealed adopting multiple adaptation practices such as agroforestry and conservation agriculture to reduce climate change impacts and increase resilience. Relatedly, all the respondents (100%) were found to practice crop/livestock systems. About 62.5% of the respondents were also involved in alternative livelihoods (e.g., trading, migration) as an adaptation strategy. This indicates the awareness of inhabitants of climate change and efforts being made to enhance their resilience. However, knowledge of agricultural insurance was found to be low, with about 79.2% of respondents having no knowledge, while all the respondents indicated not subscribing to an agricultural insurance scheme. Increased sensitization is, thus, needed to enable farmers to appreciate how agricultural insurance can further enhance their resilience to climatic changes.

North-East Zonal Council

The population sampled in this zonal council was evenly split between men and women. Farming was the main occupation (59.10%), while the rest were either engaged in other services (22.7%) or unemployed (18.2%). Sixty percent are older than 40 years, and more than half (53.3%) have received formal education. Ninety-five percent of respondents indicated not having access to water for dry season cultivation, which makes farming predominantly rain-fed, with limited or no farming activities during the dry season.

As in other zonal councils, the majority of respondents (> 90%) indicated high temperatures and shifts in the onset and cessation of rainfall as some of the climatic changes the council has been experiencing in recent years. In addition, 54.5% mentioned an increase in the incidence of drought during the cropping season and flooding (31.8%) as climate change impacts being experienced. Consequently, about 70% of respondents classified the zone as either high or very highly exposed to climate change.

Houses constructed with mud/bricks and cement constitute about 68.2%, while mud/bricks represent 31.8%. About 54.2% of respondents revealed that their homes, farms, or livestock pens have been damaged by floods before. Whereas internet availability is not a problem, accessibility is because half of respondents own phones ("Yam phones") that are not readily suitable for accessing internet while 9.1% do not own phones at all. Consequently 63.6% of respondents indicated not having access to the internet, while 36.4% have access. Those who have access complained of network unreliability and others mentioned difficulty purchasing data to access the internet. Limited access to internet could have implications on how vulnerable population can benefit from certain services that require access to the internet (e.g., CIS).

Access to inputs and services that increase the resilience of vulnerable population to climatic changes was found below. For example, 95.5% of respondents did not have access to climate-tolerant seeds. Although 68.2% have access to climate information services, these are mostly general and not location specific. Respondents were found to be knowledgeable about adaptation strategies, with 95.8% adopting multiple adaptation strategies such as agroforestry and conservation agriculture to reduce impacts and increase resilience. Most respondents (86.4%) were found to practice crop/livestock systems rather than crop only (9.1%) and livestock only (4.5%). About 50% of the respondents were also involved in other alternative livelihoods (e.g., trading, migration) as an adaptation strategy. Knowledge of agricultural insurance was found to be low, with 95.5% having no knowledge of agricultural insurance, while all the respondents indicated not subscribing to an agricultural insurance scheme. Therefore, increased sensitization is needed to enable farmers to appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Sirigu Zonal Council

The sampled population of Sirigu zonal council is made up of 61.9% men and 38.1% women. Farming is the major occupation (76.2%), while 19.0% are unemployed and 4.8% are involved in other occupations. Sixty-one percent are over 40 years, and about 62.0% have completed some type of formal education. Access to water for dry season irrigation is limited, with 95% indicating not having access. Farming is thus primarily rain-fed.

A shift in the onset and cessation of rainfall, high temperatures, and an increase in the incidence of drought during the cropping season were mentioned by more than 85% of the respondents as major climate change impacts being experienced. An increase in the frequency of high-intensity rainfall and floods was mentioned by about 23% of respondents, which seems to suggest this zonal council is less impacted by flooding than other zonal councils. However, more than 50% of respondents indicated that their house, farm, or livestock pen had been destroyed by floods in recent years. Forty-seven percent of respondents rated the zonal council as very highly exposed to climate change and 23.8% rated it as high.

For 66.7% of the respondents, mud/bricks and cement were used to build their houses, compared to 33.3% who used mud/bricks alone. According to 52.4% of the respondents, houses in the zonal council are prone to floods. Internet is available in the council, but like other areas in the municipality, access is a challenge because about a quarter (23.8%) of the residents have smartphones, while 71.4% have phones that are not suitable for accessing internet (“Yam phones”), and 4.8% don’t have phones at all. Consequently, a third of respondents (33.3%) indicated having access to the internet, compared to 66.7% who do not. In addition, the network is unstable, and the money to purchase data to access the internet is often a challenge. This presents a gloomy picture about accessing services that require internet connectivity such as climate information services.

Concerning inputs and services that increase the resilience of vulnerable population to climatic changes, most respondents (95.2%) indicated not having access to drought-tolerant seeds while less than half (47%) had access to climate information services. This may present challenges for inhabitants, especially farmers, to adapt to climate change. But 76.2% indicated adopting multiple sustainable practices (e.g., agroforestry, conservation agriculture, etc.) to reduce climate change impacts and increase their resilience. Another sustainable practice adopted by 81% is crop/livestock systems as a risk management strategy, with only 19.0% cultivating only crops (no respondent keeps only livestock). About 53.0% also indicated their involvement in alternative livelihoods (e.g., trading, migration) as an adaptation strategy. However, as with other zonal councils, as much as 85.7% of respondents had no knowledge of agricultural insurance, and 95.2% indicated not subscribing to an agricultural insurance scheme. Increased sensitization is, therefore, needed to enable farmers to appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Telania Zonal Council

The sampled population in the Telania zonal council is made up of 63.2% men and 36.6% women, most of whom are farmers (73.7%), with 26.3% being unemployed. Fifty-two percent are older than 40 years, and about 68.4% have received formal education. Farming is mainly rain-fed, with limited or no farming activities during the dry season. This is primarily due to lack of water for irrigation. Ninety-four percent of respondents indicated not having access to water for dry season cultivation.

A shift in the onset and cessation of rainfall as well as an increase in the incidence of floods were mentioned by all respondents (100%) as major climate change impacts being experienced. A significant percentage (84.2%) indicated that the zonal council has been experiencing an increasing incidence of drought in the cropping season, while 52.6% and 68.4% also indicated high temperatures and increasing incidence of high intensity rainfall, respectively, in recent years. In terms of exposure, 42.1% rated the council as very highly or highly exposed to climate change.

Mud/bricks are the major building materials, with 73.7% using it to construct their houses, while 15.8% and 10.5% used mud/bricks and cement and cement only, respectively. The high percentage of mud/brick houses makes buildings in the zonal council susceptible to flooding. Consequently, 93% of respondents revealed that either their houses, farms, or livestock pens have been damaged by floods before. Internet is available; however, accessibility is a challenge because majority of inhabitants (73.7%) own phones that are not suitable for accessing the internet (“Yam phones”). Just about 10.5% indicated having smartphone, while 15.8% have no phones at all. It was revealed that even those who have smartphones do not access the internet because of other reasons, e.g., unstable network and high cost of data to enable internet access. This can negatively impact inhabitants of the zonal council in terms of benefitting from services that may require access to the internet (e.g., CIS).

The survey revealed that inhabitants of Telania have access, although limited, to inputs and services that increase their resilience to climatic changes. Fifty-three percent, for example, have access to climate information services. But access to drought-tolerant seeds was found to be poor, with as many as 94.7% indicating not having access. Over 90% of respondents mentioned adopting environmentally sustainable practices such as agroforestry, conservation agriculture, etc., as a means of reducing climate change impacts and increase resilience. Further, 94.7% were found to practice crop/livestock systems compared to 5.3% for crops only (no respondent keeps only livestock). About 52.6% of the respondents were also involved in alternative livelihoods activities (e.g., trading, migration) as an additional adaptation strategy. These allude to the effort of inhabitants of this zonal council to adopt practices that increase their resilience to climate change. Knowledge of agricultural insurance was, however, found to be poor as and 73.7% of respondents indicated no subscriptions to any agricultural insurance scheme. Increased sensitization is, thus, needed to enable farmers appreciate how agricultural insurance can further enhance their resilience to climatic changes.

Gendered Aspects

Results of the household survey were disaggregated according to gender and analyzed to reveal gender differences in exposure, sensitivity, and adaptive capacity. Table 7 presents results based on indicators that are mainly aligned to adaptive capacity.

The results indicate that women have relatively lower capacity to adapt to climate change than men. However, this is not at an alarming proportion because, for certain indicators, women were also found to have higher adaptive capacity than men. The percentage of female respondents was lower than male respondents in all but one zonal council, which may have skewed the results, particularly in those councils where there were only two or three female respondents (e.g., Biu, Doba). This made direct comparisons a bit challenging. Specifically, the analysis revealed the following:

- Women in the KNM were better at adapting to the impacts of climate change through alternative livelihoods than men. This cut across all zonal councils in the Municipality. This was probably due to the nature of alternative livelihoods available, including trading (buying and selling) and migration to the south, which are dominated by women and young girls.
- Although knowledge of agricultural insurance was found to be limited across the zonal councils, analysis of the disaggregated data revealed that men generally had better knowledge of agricultural insurance than women, although it was the reverse in two zonal councils (Navrongo and North-East).
- Contrary to the perception that women generally have limited access to technological tools/gadgets, the data revealed otherwise. In six out of the nine zonal councils, women had higher access (percentagewise) to mobile phones than men. In some zonal councils (e.g., Biu and Doba), this could be attributed to the large difference in sample size between men and women. However, women predominantly owned “yam” phones (percentages in brackets) which have limited functionality compared to the smartphones to which men had higher access.
- Men generally had higher access to internet than women, although in the North-East where equal numbers of men and women were interviewed, a higher percentage of women had access to internet than men. Men’s higher access to internet is possibly due to their higher access to smartphones.
- Access to climate tolerant seeds was mixed, although both sexes had very limited access to these seeds. The same was observed for access to water for dry season irrigation. Apart from Biu where the 50% access for women is likely due to the low number of women interviewed (two), both sexes had no or extremely low access to water for irrigation.
- Men had higher access to CIS than women in all zonal councils. Whereas most respondents indicated the radio as their main source of CIS, respondents who indicated private service delivery companies (e.g., esoko, ignatia) as their source were predominantly men. Although “yam” phones are suitable for receiving CIS information, the observed higher percentage for men could be partly attributed to their increased access to smartphones and internet access.

Table 7. Gender differences in respondents' capacity to adapt to climate change impacts

Zonal council	Gender (sample population)	Access to Phones ("yam" phones)	Access to internet	Access to CIS	Access to clim. tolerant seed	Access to water for irrigation	Alternative livelihood	Know. Agric insurance
Biu	Male (13)	92 (62)	38.5	69	0	8	56	54
	Female (2)	100	0	0	0	50	100	50
Doba	Male (14)	86 (36)	42.9	71	57	14	63	64
	Female (3)	100 (67)	33.3	33	0	0	100	0
Manyoro	Male (12)	100 (50)	50	92	8	0	25	42
	Female (7)	100 (29)	42.9	43	14	0	57	43
Naaga	Male (13)	100	15.4	77	31	0	33	54
	Female (8)	86 (57)	37.5	63	38	0	50	25
Navrongo	Male (16)	88 (13)	75	75	25	8	57	25
	Female (11)	100 (46)	60	55	18	27	71	36
Yua	Male (16)	94 (63)	40	56	25	0	36	25
	Female (8)	100 (71)	42.9	50	25	0	60	13
North-East	Male (11)	100 (73)	27.3	91	0	0	50	0
	Female (11)	90 (30)	45.5	63	9	0	56	9
Sirigu	Male (13)	92(69)	38.5	62	8	8	40	15
	Female (8)	100 (75)	25	38	0	0	57	13
Telania	Male (12)	75 (67)	0	75	0	0	38	0
	Female (7)	100 (86)	0	29	14	0	0	0

4.3.2 Vulnerability Index Results

Tables 8-10 present the indicators of the three components (exposure, sensitivity, and adaptive capacity) used to quantitatively assess the vulnerability of the KNM to climate change. The tables further present the measure of vulnerability obtained from the various data sources (model, household survey, GIS/RS), and the rescaled value (see section 4.2, in blue italics). Figure 10 provides maps of the three vulnerability components derived from values in Table 11.

Table 8. Exposure indicators per zonal council, measure of vulnerability, and rescaled value (in blue italics)

Zonal councils	Biu	Naaga	Doba	Navrongo	Telania	Sirigu	North_East	Manyoro	Yua
Exposure calculation	**0.7127**	**0.8843**	**0.4824**	**0.6087**	**0.2941**	**0.0571**	**0.0000**	**0.1063**	**0.1568**
Mean annual rainfall	948.5	955.5	946.2	976.6	940.0	918.0	915.7	922.8	930.0
	0.539	*0.653*	*0.501*	*1.000*	*0.399*	*0.038*	*0.000*	*0.116*	*0.235*
Minimum temperature	23.1	23.1	23.0	23.0	22.9	22.9	22.9	22.9	22.9
	0.793	*1.000*	*0.485*	*0.374*	*0.223*	*0.068*	*0.000*	*0.095*	*0.094*
Maximum temperature	34.1	34.2	34.0	34.0	34.0	33.9	33.9	33.9	33.9
	0.806	*1.000*	*0.461*	*0.452*	*0.260*	*0.065*	*0.000*	*0.108*	*0.141*

Naaga, with a score of 0.8843, is the most exposed zonal council. Located in the southern-most part of the KNM, its exposure is partly influenced by the proximity of the White Volta River which often overflows its banks after high intensity rains. The north-eastern zonal council has the lowest relative exposure and the zonal councils located in the northwest (Telania and Navrongo) are moderately exposed. The lower exposure of the north-eastern zonal councils may be a result of the limited extent of the gridded rainfall and temperature data from which the indicators were extracted, as they only partially covered the zonal council.

Table 9. Sensitivity indicators per zonal council, measure of vulnerability, and rescaled value (in blue italics)

Zonal councils	Biu	Naaga	Doba	Navrongo	Telania	Sirigu	North_East	Manyoro	Yua
Sensitivity Calculation	**0.4462**	**0.3392**	**0.5249**	**0.1951**	**0.2502**	**0.4243**	**0.4002**	**0.3043**	**0.4449**
Mud (bricks)	46.67	38.10	76.47	11.11	73.68	33.33	31.82	15.79	87.50
	0.467	*0.381*	*0.765*	*0.111*	*0.737*	*0.333*	*0.318*	*0.158*	*0.875*
House flood prone	53.33	47.62	52.94	25.93	15.79	52.38	59.09	47.37	54.17
	0.533	*0.476*	*0.529*	*0.259*	*0.158*	*0.524*	*0.591*	*0.474*	*0.542*
House destroyed	93.33	61.90	76.47	29.63	21.05	52.38	54.55	36.84	54.17
	0.933	*0.619*	*0.765*	*0.296*	*0.211*	*0.524*	*0.545*	*0.368*	*0.542*
Farm flood prone	93.33	61.90	64.71	14.81	15.79	57.14	59.09	31.58	41.67
	0.933	*0.619*	*0.647*	*0.148*	*0.158*	*0.571*	*0.591*	*0.316*	*0.417*
Flood prone	38.22	44.76	40.93	9.51	19.21	28.30	27.55	22.35	32.70
	0.382	*0.448*	*0.409*	*0.095*	*0.192*	*0.283*	*0.276*	*0.223*	*0.327*

Zonal councils	Biu	Naaga	Doba	Navrongo	Telania	Sirigu	North_East	Manyoro	Yua
Cropland flood	25.29	12.29	76.03	59.35	53.50	77.40	83.19	81.49	82.69
	0.253	*0.123*	*0.760*	*0.594*	*0.535*	*0.774*	*0.832*	*0.815*	*0.827*
Built-up flood	0.04	0.07	0.79	0.79	0.03	2.45	0.58	0.18	0.26
	0.000	*0.001*	*0.008*	*0.008*	*0.000*	*0.025*	*0.006*	*0.002*	*0.003*
Population flood	6.71	4.68	31.60	4.95	1.09	36.07	4.32	7.84	2.74
	0.067	*0.047*	*0.316*	*0.049*	*0.011*	*0.361*	*0.043*	*0.078*	*0.027*

Biu, Doba, and Yua are the most sensitive to the impacts of climate change mainly because of the prevalence of houses constructed with mud and the high susceptibility of houses and farms in these zonal councils to flooding. Doba and Biu in particular reported high percentages in terms of houses destroyed by flooding and area of farms prone to flooding. Navrongo, on the other hand, was found to be the least sensitive because of low likelihood of flooding and the predominance of houses constructed with cement (or a combination of cement and mud).

Table 10. Adaptive capacity indicators per zonal council, measure of vulnerability, and rescaled value (in blue italics)

Zonal councils	Biu	Naaga	Doba	Navrongo	Telania	Sirigu	North_East	Manyoro	Yua
Adaptive capacity calculation	**0.5515**	**0.342**	**0.4346**	**0.3603**	**0.445**	**0.3828**	**0.3798**	**0.4926**	**0.5076**
Mobile owner (No)	93.3	85.7	88.2	7.4074	84.2	95.2	90.9	100	91.7
	0.933	*0.857*	*0.882*	*0.0741*	*0.842*	*0.952*	*0.909*	*1*	*0.917*
Internet access	26.7	14.3	13.3	37.037	0	33.3	36.4	47.4	37.5
	0.267	*0.143*	*0.133*	*0.3704*	*0*	*0.333*	*0.364*	*0.474*	*0.375*
Distance market	53.33	0.00	5.88	55.56	100.00	23.81	22.73	52.63	100.00
	0.467	*1.000*	*0.941*	*0.444*	*0.000*	*0.762*	*0.773*	*0.474*	*0.000*
Distance health	60.00	0.00	11.76	44.44	57.89	19.05	18.18	52.63	45.83
	0.400	*1.000*	*0.882*	*0.556*	*0.421*	*0.810*	*0.818*	*0.474*	*0.542*
Access CIS	60.00	23.81	58.82	44.44	52.63	47.62	68.18	42.11	50.00
	0.400	*0.762*	*0.412*	*0.556*	*0.474*	*0.524*	*0.318*	*0.579*	*0.500*
Climate seeds	100.00	23.81	17.65	18.52	0.00	4.76	22.73	10.53	12.50
	0.000	*0.762*	*0.824*	*0.815*	*1.000*	*0.952*	*0.773*	*0.895*	*0.875*
Adap (multiple)	73.33	80.95	94.12	48.15	94.74	76.19	59.09	68.42	95.83
	0.267	*0.190*	*0.059*	*0.519*	*0.053*	*0.238*	*0.409*	*0.316*	*0.042*

Zonal councils	Biu	Naaga	Doba	Navrongo	Telania	Sirigu	North_East	Manyoro	Yua
Type of cropping	80.00	100.00	94.12	48.15	94.74	80.95	86.36	78.95	100.00
	0.200	*0.000*	*0.059*	*0.519*	*0.053*	*0.190*	*0.136*	*0.211*	*0.000*
Water Dry Sea	13.3	4.8	47.1	25.9	5.3	25.9	8.7	47.1	4.2
	0.133	*0.048*	*0.471*	*0.259*	*0.053*	*0.259*	*0.087*	*0.471*	*0.042*
Insurance knowledge	46.67	42.86	47.06	29.63	0.00	14.29	4.55	42.11	20.83
	0.533	*0.571*	*0.529*	*0.704*	*1.000*	*0.857*	*0.955*	*0.579*	*0.792*
Insurance subscribe	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Biu, Yua, and Manyoro came up as the zonal councils with the high capacity to adapt to climate change impacts, while Naaga has the lowest capacity. Key indicators that contributed to the high adaptive capacity of the three zonal councils include ownership of mobile phones, access to markets and health facilities (less than 30 minutes), and access to CIS. On the other hand, limited access to markets and health facilities in less than 30 minutes contributed to Naaga's low adaptive capacity.

Table 11 provides a summary for the three components, which is essentially an average of the rescaled values of all indicators in each component. The right column shows the index of vulnerability for each zonal council, which was derived from the application of equation 1 (that is described in section 3.5.3).

Table 11. Summary results of the quantitative climate change vulnerability assessment for Kassena Nankana Municipality

Zonal council	Exposure	Sensitivity	Adaptive capacity	Vulnerability Index
Naaga	0.8843	0.3392	0.3420	-0.0421
Doba	0.4824	0.5249	0.4346	-0.1813
Biu	0.7127	0.4462	0.5515	-0.2335
Navrongo	0.6087	0.1951	0.3603	-0.2415
Sirigu	0.0571	0.4243	0.3828	-0.3586
Telania	0.2941	0.2502	0.4450	-0.3714
North_East	0.0000	0.4002	0.3798	-0.3798
Yua	0.1568	0.4449	0.5076	-0.4379
Manyoro	0.1063	0.3043	0.4926	-0.4603

Figure 10. Maps of the three vulnerability components derived from values in Table 10

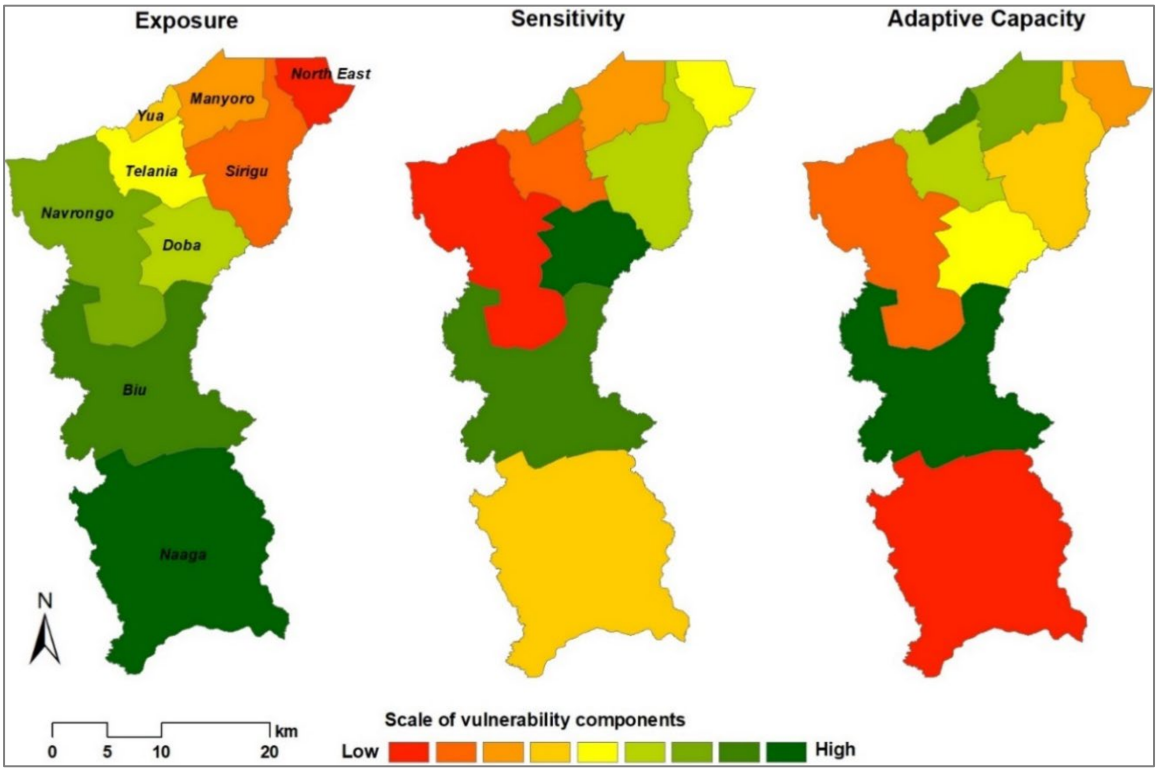
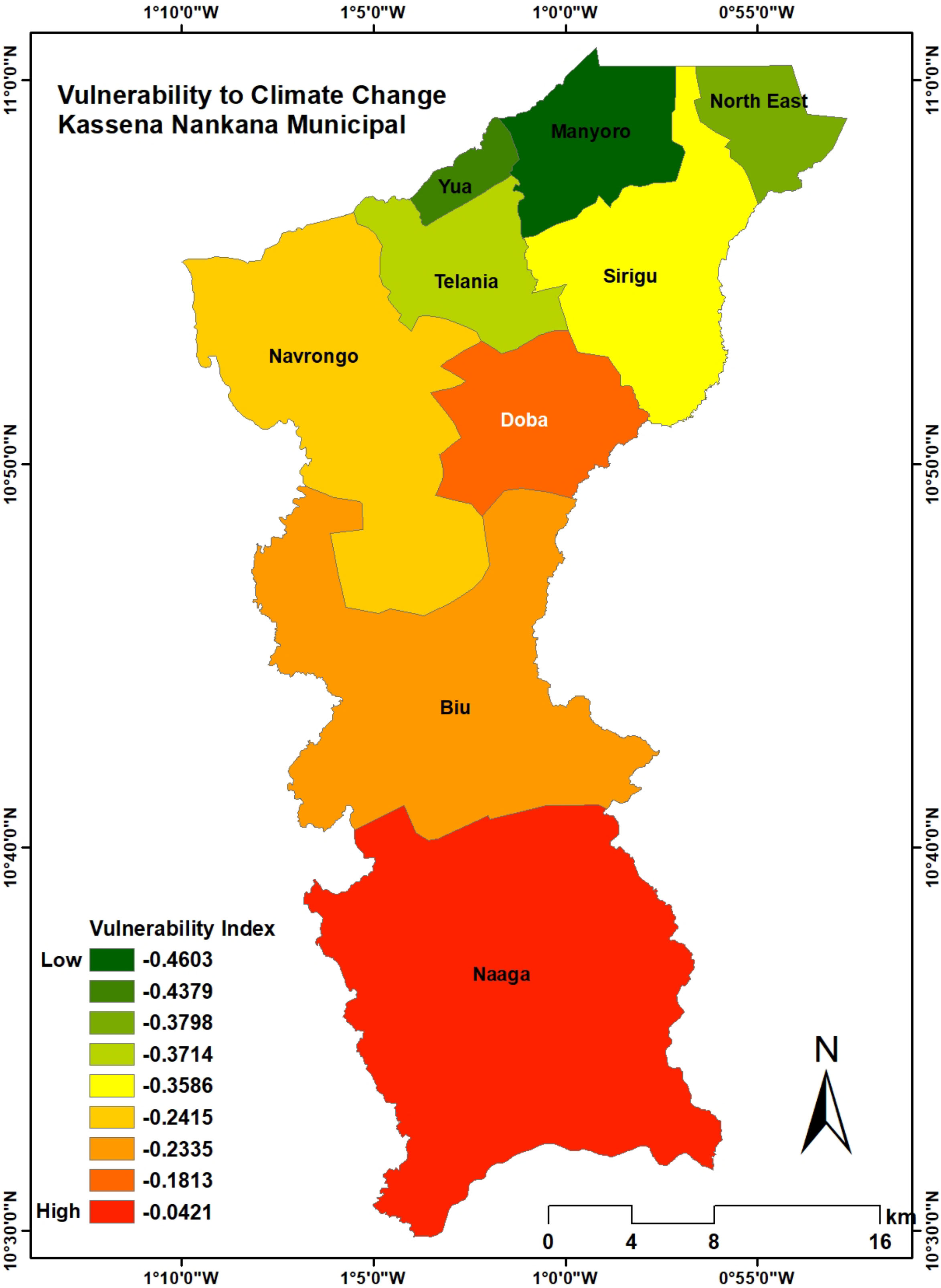


Figure 10 includes maps that illustrate the information in Table 10. The exposure map shows that the central to south part of the Municipality are highly exposed to changes in rainfall and temperature, with Naaga being the most exposed. The north-eastern part, however, has low exposure while the north-western side (Telania and Navrongo) are moderately exposed. The sensitivity map shows that Biu and Doba are the most sensitive to the impacts of climate change, while Navrongo is the least sensitive. Some zonal councils are highly sensitive to climate change, while having high to moderate capacity to adapt to the changes. The adaptive capacity map indicates that Biu and Yua zonal councils fall into this category. The maps show that the Manyoro and Telania zonal councils are moderately sensitive but have high adaptive capacity. Navrongo, which is the capital of the Municipality, has a low capacity to adapt to climate change and is highly exposed to changes in climate variables, but scores lowest on sensitivity. Naaga has the least adaptive capacity, is highly exposed, and is moderately sensitive.

Figure 11 presents the vulnerability index map of the KNM. The index ranges from -0.46 (lowest) in Manyoro zonal council to -0.04 (highest) in Naaga zonal council. The negative sign of the index for all zonal councils indicates the adaptive capacity of all councils, when quantified, is higher than the product of the exposure and sensitivity elements. This suggests some level of adequacy in terms of adaptive capacity, and those zonal councils with lower indexes (up to -1) have higher adaptive capacity.

Figure 11. Vulnerability Index map of Kassena Nankana Municipality



The negative sign of the indices is at variance with the result of the national-level quantitative vulnerability mapping conducted as part of Ghana's Fourth National Communication to the UNFCCC (Environmental Protection Agency, 2020), which found most of the districts in northern Ghana to have a positive vulnerability index (KNM, then Kassena Nankana East had +0.02). A positive index indicates that the combined effects of exposure and sensitivity is higher than adaptive capacity, which suggests the need to strengthen the adaptive capacity of the population in question.

Differences in the indicators used and the data collection approaches adopted by the respective analyses is a possible reason for the difference in the level of vulnerability between this analysis and that of the Fourth National Communication. For example, exposure elements used in the national level analysis included variations in mean annual rainfall and temperature while the current study included only absolute values of mean annual rainfall, and minimum and maximum temperature. Further, the national-level analysis included projected future changes in rainfall and temperature while the current study excluded such information due to data unavailability. On the other hand, indicators used to quantify adaptive capacity in the sub-municipal analysis, which were derived from household surveys, were much more comprehensive than those used in the national-level analysis, which were mainly extracted from previous censuses that were not purposely designed to assess climate change vulnerability.

Limitations

The application of equation 1, as recommended by the IPCC, requires that for each component, past/current and future indicators are included in assessing climate change vulnerability. However, in this study, only past and/or current data were used in the analysis. This is primarily due to unavailability of appropriate data to provide future projections of the indicators adopted. The next section, however, provides a summary of climate change projections for the KNM and the potential impacts of these projections on the vulnerability of populations in the Municipality.

Analysis

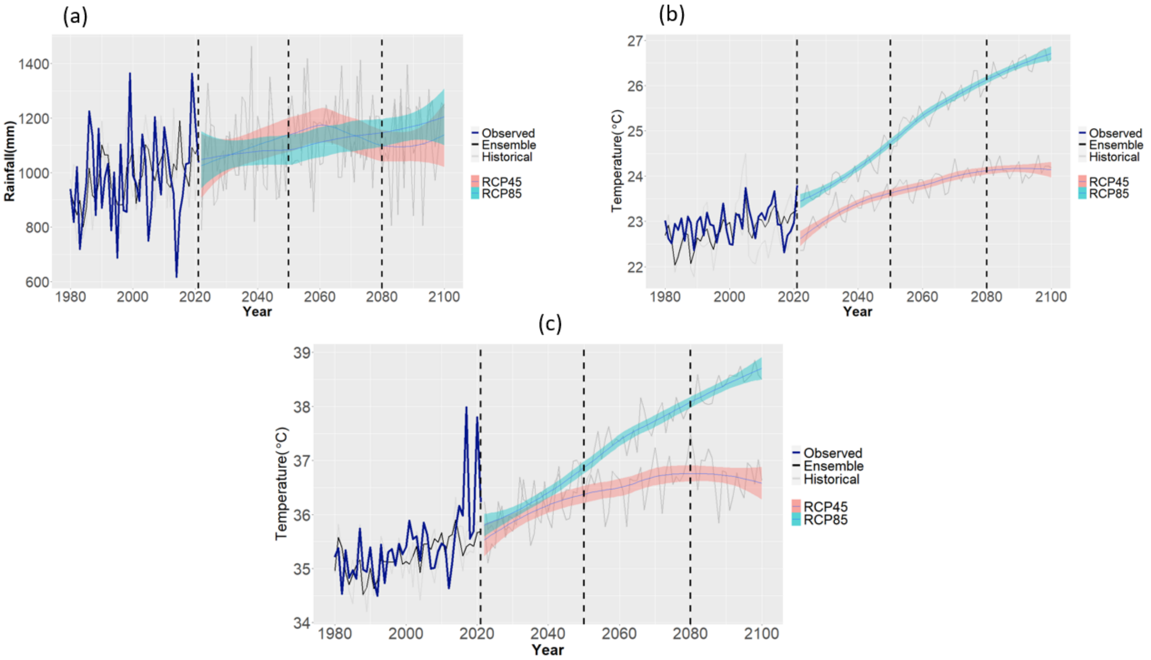
The current analysis provides intra-municipal differences in climate change vulnerability across the Municipality. This information, which the national-level analysis did not provide, is critical for designing targeted interventions through adaptation planning. For example, future Medium Term Development Plans should consider the variations in vulnerabilities across the zonal councils in designing interventions. A review of the index map, for example, shows a north-south gradient in climate change vulnerability across the zonal councils of KNM. Manyoro, North-East, and Yua zonal councils, all in the north of the Municipality, have the lowest vulnerability to climate change. Navrongo, Doba, and Biu zonal councils in the central part have moderate to low vulnerability while Naaga, the southern-most zonal council has the lowest vulnerability in the Municipality. Obviously, the high adaptive capacity of the northern zonal councils, coupled with their low exposure and sensitivity, makes them less vulnerable, while the low adaptive capacity of Naaga makes it highly vulnerable to climate change. Periodic updating of the vulnerability index with new data is needed to constantly monitor the condition of zonal councils to enable effective decision making, especially on interventions to reduce the impacts of climate change.

4.4 Assessing Future Climate Change Risk

4.4.1 Summary of Climate Change Projections

Figure 12 shows climate projection scenarios for Navrongo, the capital of Kassena-Nankana district. Historical data of climate trends (1980-2020) underlies the projections to the year 2100 for rainfall, and minimum and maximum temperatures for two scenarios (representative concentration pathway RCP 4.5 and RCP 8.5). Both scenarios project varying rainfall from 1,200 mm to 1,300 mm through the end of the century. The mean annual rainfall is expected to increase steadily (from 987 mm to 1,074 mm) until the middle of the century. After that point, some level of reduction in mean annual rainfall is anticipated under the RCP 4.5 scenario and increases are expected under the RCP 8.5 scenario (Figure 12a). These findings are in line with previous studies over Northern Ghana (e.g., Larbi et al. 2021; Klutse et al. 2021; MacCarthy et al. 2022). For example, Klutse et al. (2021) projected an increase in inter-annual rainfall variability and a slight increase in mean annual rainfall amounts in some locations (e.g., Tamale, Yendi, Wa, and Navrongo) in northern Ghana over the period 1980-2080 under the RCP 8.5 scenario.

Figure 12. Projected mean annual (a) rainfall, (b) minimum, and (c) maximum temperature over Navrongo



Source: Klutse and Asare, 2023.

In terms of temperature, warm nights and days are projected (Figure 12b and 12c), with the nighttime temperature projected to rise more quickly than the daytime temperature. By the middle of the century, the average annual nighttime temperature is projected to increase by 1°C (i.e., from 22.8°C to 23.6°C), while the daytime temperature is expected to increase from 35.2°C to 36.1°C. The increase in minimum and maximum temperature is projected to be much higher under the RCP 8.5 scenario. According to Klutse et al. (2020), the minimum temperature over the Northern Ghana is projected to increase by 2.5°C, while the maximum temperature will also increase by 2°C under RCP 8.5 scenario over the period 1961-2080.

4.4.2 Potential Impacts and Future Climate Change Risks

Agriculture

Due to the predominance of rainfed agriculture, the agricultural sector is more exposed to climate change and harsh weather (Yiran et al., 2017). The Kassena Nankana district is predicted to see rising temperatures and irregular rainfall patterns over the long term, which are predicted to have a detrimental effect on crop yield, livestock numbers, and productivity. According to Fredua et al. (2018), maize yields are projected to decline by 9% under an RCP 4.5 pathway and 39% under an RCP 8.5 pathway by mid-century (2040-2069). Similarly, MacCarthy et al. (2022) found that the productivity of soybean in Northern Ghana will decrease (3% to 13.5% across Global Climate Models and Regional Climate Projections) due to climate change (higher temperatures and unpredictable rainfall). Compared to RCP 4.5, the anticipated loss in soybean output is expected to be greater under RCP 8.5. The inter-annual rainfall changes are predicted to lead to an increase in extreme occurrences like floods and drought in the municipality. Because the population is largely rural and exposed to the threats of drought, flooding, and unpredictable precipitation, future food security is at risk.

Water Resources

Future water resources in the Kassena Nankana Municipality will be under threat due to the high likelihood of excessive water loss from the projected 1.3°C rise in temperature and associated increased evapotranspiration. Water resource infrastructure such as dugouts and small reservoirs (dams) may dry up. According to previous studies, the White Volta basin, where Kassena Nankana is situated, would experience a decline in available water as the temperature rises. Larbi et al. (2021) projected a decrease in surface runoff and water yield by 38.7% and 42.8%, respectively, in the region under a temperature increase of 1.3°C. Similarly, Kankam-Yeboah et al. (2013) reported that streamflow will decrease by 21.6% and 50.1% in the 2020s and 2050s, respectively, in the White Volta basin due to temperature increase.

Human Health

The health of the residents of the Kassena Nankana Municipality will be impacted by rising temperatures combined with excessive humidity levels. Due to the anticipated rise in extreme events (i.e., floods, droughts), diseases like cholera and diarrhea that were reported during stakeholders' workshop at the Municipality may become more prevalent in the future. Additionally, the area may see an increase in diseases like CSM, which thrives in high temperatures (Akanwake et al., 2022). Extreme events like floods have reportedly destroyed sanitation infrastructure in the past, causing cholera outbreaks. Therefore, there is a chance that cholera outbreaks will become more frequent in the future because of the increased incidence of extreme events in the region. According to Baffoe-Bonnie et al. (2008), the projected rise in temperature and decrease in rainfall will also lead to an increase in measles cases. In addition, it is anticipated that other diseases like malaria may spread rapidly in areas with high temperatures and inadequate drainage systems (Nelson and Agbey, 2005).

Biodiversity/Forest

In the Kassena Nankana Municipality, desertification could become more severe because of climate change and unsustainable land use practices. The expected rise in temperature and the wide variability in rainfall will put the environment under stress. Given the plethora of biophysical and human-related problems that continue in northern Ghana, including erosive rains, recurrent droughts, deforestation, and overgrazing, the rate of vulnerability is expected to increase. In their study, Gyasi et al. (2008) discovered a close association between seasonal climate parameters and the vegetation's overall adaptability in Ghana's Upper East Region.

Energy

The primary source of electricity in the municipality is climate-dependent hydropower from the Volta Lake. The production of hydropower will be impacted by the anticipated rise in temperature, significant annual rainfall variability, a similar condition in the regions south of the Kassena Nankana. According to historical meteorological data and hydrological models, the Volta Lake's water level is quite sensitive to even modest fluctuations in rainfall. The lake's water level is unpredictable due to the present mixed projection of rainfall and high temperatures based on global climate models. According to an IEA (2020) assessment, in scenarios with temperature increases below 2°C and over 3°C, respectively, Ghana's hydroelectric capacity at the Akosombo, Biu, and Kpong facilities is expected to decline by 0.2% and 0.24% for the period 2020–2099. The Municipality’s socioeconomic activities will be impacted by the anticipated decline in electricity production. Additionally, because warm nights and days are predicted to grow while cold days and nights will continue to drop until the end of the century, the expected rise in temperature will result in an increase in the demand for energy for cooling during both the day and the night.

5. Policy Recommendations

The future climate projections reveal a potential increase in mean annual rainfall up to the middle of the century. Temperature is also expected to increase, with a projected increase in warm nights and days, and a decline in cold days and nights, until the end of the century. Nighttime temperature is projected to rise more quickly than that of daytime, with projected increases of 1°C and 0.9°C, respectively. These projections call for urgent policy shifts and actions to increase the resilience of vulnerable populations and reduce the impacts of projected increases. This chapter outlines key policy recommendations, based on the findings of the assessment, for consideration by policy-makers and other relevant stakeholders. The recommendations focus on capacity strengthening, research and development, education and awareness creation, provision of essential services, and incentivizing the adoption of sustainable resource management.

- **Strengthen the capacity of sub-national climate change related institutions**. Sub-national offices of institutions such as the Ghana Meteorological Agency, National Disaster Management Organization, district agricultural offices, etc., play a critical role in data collection, analysis, and provision of advisories that enable vulnerable population to adapt to climatic changes. However, engagement with these offices during the assessment revealed very limited technical, human, and financial capacity to carry out their mandate. For example, an up-to-date event database that provides information on the number of disasters (floods, droughts, windstorms, etc.) that have occurred in the Municipality and associated information was not available. Capacity to collect and analyze such data is limited. Lack of such data limits the design of appropriate interventions and effective decisions. This is especially critical for zonal councils such as Biu, Doba, and Yua that are highly sensitive to extreme climate events like floods. These zonal councils will benefit from early warning systems that can enhance their preparedness for such events and reduce impacts.

  Policies should increasingly shift excessive focus from national level capacity strengthening to sub-national levels in line with Ghana's decentralization agenda. As policy implementation takes place at the district levels, institutions at this level must be appropriately capacitated. To ensure effective implementation, officials at sub-national offices need to be regularly educated on national policies and government's commitments under international treaties (e.g., the Paris Agreement). For example, it was revealed during key informant interviews that most officials are not very conversant with Ghana's Nationally Determined Contribution and National Adaptation Plan process. This can significantly impact implementation and subsequently address the vulnerabilities of the population.

- **Research into climate-resilient building materials**. Household surveys conducted at zonal council level revealed that over 50% of buildings in the Kassena Nankana Municipality are either constructed from mud or a combination of mud and cement. These buildings are very susceptible to climate extremes such as floods. Zonal councils such as Doba and Biu were found to be highly sensitive due in part to the high percentage of mud buildings and the ease with which they are destroyed by floods. However, mud is a preferred building material in most of northern Ghana due to high temperatures and the cooling effect that mud provides as a building material. Considering the projected rise in temperatures, including rise in nighttime temperatures, the use of building materials that reduce the impacts of high temperatures on residents will be extremely beneficial. This calls for increased research into developing appropriate materials that can help residents endure high temperatures and are not susceptible to hazards such as floods, which are also projected to increase. Policies should focus on the sustainable use of indigenous materials to develop climate-resilient housing infrastructure in high temperature zones like KNM. Priority should be given to highly sensitive zonal councils in implementing this recommendation.

- **Develop climate resilient water, sanitation, and hygiene (WASH) infrastructure**. Sanitation-related health hazards such as cholera are expected to increase because of projected increases in high intensity rainfall. This means sanitation infrastructure in the Municipality, be it residential, educational, or health, should be designed or redesigned to be resilient against these projected changes. Sanitation policies should target sub-national vulnerabilities and provide direction on the development of WASH infrastructure that is resilient to climate change. Policies should also target the possible reuse of waste (e.g., waste-to-energy processes, composting waste and using manure for gardening, etc.), especially in public facilities such as schools and hospitals. While this recommendation is critical for the whole municipality, zonal councils that are high exposed (e.g., Naaga, Biu, and Navrongo) should be prioritized when developing interventions.
- **Irrigation development and sustainable water management**. Agricultural production under rainfed cultivation is projected to suffer due to projected changes in rainfall and temperature. Whereas the government's policy of one-village, one-dam may have provided opportunities for more farmers to be engaged in all-year cultivation, results of the survey revealed that most farmers feel helpless during the dry season because of lack or limited access to irrigation infrastructure. Apart from Doba and Manyoro that had about 50% of respondents having access to water for dry season irrigation, all zonal councils had percentages of less than 25%, with Yua, Naaga, Telania, and North-East having 4.2%, 4.8%, 5.3%, and 8.7%, respectively. Government policies and programs should target the development of more sustainable irrigation infrastructure, fitted with environmentally friendly lifting technologies such as solar pumps, to support dry season cultivation as well as supplemental irrigation during the rainy season in or around these zonal councils. In addition to the development of irrigation infrastructure, the existing irrigation policy (2011) needs revision to include new efficient and sustainable water use technologies that enable high crop productivity with less water. The adoption of such technologies is critical for achieving food security in a future world with less water but more people to feed. Opportunities should be provided for smallholder farmers to be trained in the use of such technologies through an efficient and adequately capacitated agricultural extension service.
- **Support entrepreneurship in climate innovation**. Climate change impacts, especially on agriculture, is inducing migration of young people from the north to southern Ghana. These young people engage in menial (e.g., kayaye) and environmentally unsustainable jobs (e.g., scrap metal and electronic waste collection, burning, etc.). Instead of encouraging them to migrate, deliberate and targeted policies should be made to support these young people to develop sustainable businesses. Several business opportunities exist in the use of natural resources as well as value addition that can be explored. Resource reuse, e.g., recycling of wastewater into other productive uses, is an opportune area of consideration. Youth and entrepreneurship policies must deliberately target sub-national levels and support the youth to turn the climate crises into a climate blessing/opportunity.

- **Increase smallholder farmers' accessibility and use of advisories and other services**. Smallholder farmers need accurate, up-to-date, and location-based climate and agronomic information to take critical farming decisions in a changing climate. In addition, smallholder farmers need to be buffered against crop failure from extreme events such as floods and droughts. Unfortunately, more than 50% of smallholder farmers in the Municipality lack access to climate and agronomic information, while knowledge of, or subscription to, agricultural insurance is non-existent. Naaga was particularly found to be vulnerable in this regard, with just about 23% of respondents having access to CIS. Agricultural policies should emphasize and propose strategies to increase smallholder farmers' access to important climate information advisories. In addition, the national policy on agricultural insurance which is under development should have a specific target and device strategies to enable smallholder farmers benefit from risk transfer schemes. Smallholder farmers need agricultural insurance the most as a means of safeguarding their production against climate-induced losses. Unfortunately, they are the most left out.
- **Increase community-level sensitization on sustainable resource management**. Despite attesting to the impacts of climate change, vulnerable populations are often oblivious of the contribution of their actions, especially in the exploitation of natural resources, to changes in climate patterns. Examples are excessive deforestation, sand mining, or cultivation in river buffer zones. Whereas these practices are sometimes a matter of livelihood, e.g., cutting trees for charcoal production, there's little or no education on managing these resources sustainably. There is the need for increased education and sensitization on the importance of sustainable use of forest and other natural resources at the community level. For maximum impact, this sensitization campaigns should be carried out in local languages that community members can understand. Other means of education such as drama may be employed to increase awareness. On deforestation, in addition to increased sensitization, policies should target the development of parklands with economically less important tree species purposely for charcoal production and/or firewood usage. This will reduce the pressure on tree species with other uses, such as shea.
- **Incentivize recommended practices and discourage unsustainable practices**. Policies often outline the need to pursue certain environmentally sustainable practices without providing the requisite incentives for adoption. Most smallholder farmers have, for many years, become used to certain traditional agricultural practices that may not be environmentally sustainable. However, they continue their traditional practices because they are comfortable with them. Such farmers need an incentive to shift and adopt new production practices that achieve better results and have less impact on natural resources and the environment. Agricultural policies must make these provisions to encourage more smallholder farmers to adopt climate smart agricultural practices. On the other hand, policies must be developed or revised to incorporate harsher punishment for those who embark on unsustainable exploitation and practices in agriculture and forestry.

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Appendix 1. Existing Secondary Data Sources on Key Weather Elements in Kassena Nankana District

Table 12. Existing secondary data sources on key weather elements in Kassena Nankana District

Study title & author(s)	Data	Data description	Data source	Data gaps
Climate change adaptation through agroforestry: The case of Kassena Nankana West District, Ghana. **Apuri et al., 2018**	Rainfall and temperature.	The data were collected for the period 1984-2015. The rainfall trends were analyzed for three decades to validate farmers perception on changing local climate. The annual rainfall for the 30-year period shows a decreasing linear trend. The rainfall data analyzed for onset and cessation show the April and May and cessation was found to be October. Both maximum and minimum temperature from weather station records show increasing temperature.	Ghana Meteorological Service -Navrongo	NA
Which is more important to sorghum production systems in the Sudano-Sahelian zone of West Africa: climate change or improved management practices? **Adam et al., 2020**	Baseline climate data from observed weather (1980-2009). Future climate from five Global Circulation Models (GCMs: 2040-2069) in two Representative Concentration Pathways (RCP 4.5 and 8.5).	The baseline data used in the study consisted mainly of daily observations of rainfall, solar radiation, and temperatures which were sourced from the AGRHYMET Regional Center for the 1980-2010 period. Missing data were replaced with corresponding AgMERRA time series data (Ruane et al., 2015), with bias adjustment according to a comparison between AgMERRA and the monthly climatology of the observed station. 5 GCMs were selected for each site from a total of 29 GCMs that best described the climate of each site where a scatterplot combining the changes in temperature and precipitation compared to the baseline. RCP 8.5 scenario temperatures were expected to increase by up to 2.72°C in Navrongo. For precipitation, the expected changes were more contrasting, with a -3% decrease in the driest scenario and a +12% increase in the wettest in Navrongo.	AGRHYMET Regional Center, Ghana Meteorological Agency	NA

Study title & author(s)	Data	Data description	Data source	Data gaps
Climate Change Impact and Variability on Cereal Productivity among Smallholder Farmers under Future Production Systems in West Africa. **MacCarthy et al., 2021**	The weather variables used in the study included daily minimum and maximum temperature, rainfall and solar radiation. GCMs data.	The climate data for the period from 1980 to 2009 were obtained from the Ghana Meteorological Agency for Navrongo. The study also used five GCMs based on a scatterplot of the average seasonal temperature and the seasonal rainfall for the locations, which was used to identify the cluster of GCMs that fall into each of RCP 4.5 and 8.5. The ensemble changes in projected temperatures for the Navrongo site were 1.50 and 2.12°C with CVs of 22% and 21% for RCP 4.5 and RCP 8.5, respectively. The ensemble changes in projected rainfall amount were +2.8 and +4.6% for the RCP 4.5 and RCP 8.5, respectively.	Ghana Meteorological Agency, Navrongo	NA
Comparing farmers' perception of climate change and variability with historical climate data in the Upper East Region of Ghana **Amadou et al., 2015**	Climate data including rainfall and temperature were collected for this study.	Data from this research was used to compute the annual average temperature (minimum and maximum) and rainfall. Other parameters related to the rainy season such as onset, cessation dates and number of days without rain (i.e., drought) were computed over a period of 40 years because only data for 1970-2010 were recorded on a daily basis.	Ghana Meteorological Agency, Navrongo.	NA
Food security and climate change in drought-sensitive savanna zones of Ghana **Armah et al., 2011**	Rainfall and temperature data were collected for this study.	These data were analyzed to predict the changes and trends and how these changes influence crop production. These data were also used to model the onset of the of rains based on the Markov chain stochastic process for the drought sensitive from 1960-2008. The model results indicate that 6th May (day 127) was the average start of rains for both the Sudan savanna and Guinea savanna agroecological zones. According to the study, whilst other area such as Tamale, and Salaga had delayed rains, Navrongo had slightly earlier rains.	Ghana Meteorological Agency, Navrongo	There is the need to strengthen the institutional capacity for research and policy development. Limited research at various spatial scales (plot level, farm household, community, and national).

Study title & author(s)	Data	Data description	Data source	Data gaps
Rainfall and temperature changes and variability in the Upper East Region of Ghana **Issahaku et al., 2016**	Meteorological data including temperature and rainfall.	Data were taken from all weather stations in the Upper East Region from 1954 to 2014 from the Ghana Meteorological Agency. Missing data were estimated by linear interpolation. These datasets were averaged monthly and used for modelling. The data analyzed showed a downward rainfall trend. Rainfall is most likely to start from the month of April to the month of August each year when it would be heavier and starts to decline again in September. The projections revealed that rainfall was trending downward, and that both nighttime and daytime temperatures were linear and trending upward.	Ghana Meteorological Agency, Navrongo	Some past studies did little to identify the months or periods the Upper East Region would be hot or cold.
Spatiotemporal analyses of impacts of multiple climatic hazards in a savannah ecosystem of Ghana **Yiran & Lindsay, 2016**	Rainfall data from Ghana Meteorological Agency (GMet).	These data were analyzed using a SPI (Standard Precipitation Index). The SPI was calculated for 1-month, 3-month, 6-month, 9-month and 12-month timescales and analyzed from 1988 to 2012 because most stations had reliable data in that period. These data were used to calculate dry spells. High temperatures also affected public health which is confirmed with records from the Ghana health directorate that the highest cases of CSM occurred in 2012.	Ghana Meteorological Agency, Navrongo	Little research on the frequency and alternate occurrences of different types of natural hazards have cumulatively affected human livelihoods and socio-economic conditions.
A time series analysis of weather variability and all-cause mortality in the Kassena-Nankana Districts of Northern Ghana, 1995-2010. **Azongo et al., 2012**	Weather data (daily min, max) temperature and daily precipitation data) from January 1995 to December 2010 were obtained from the Navrongo Meteorology Station.	Daily mean temperature data were aggregated from daily minimum and maximum temperatures, an index designed to better estimate exposure as it uses multiple observations. Further modeling was carried out to assess the association of mean daily temperature and precipitation on all-cause mortality by age groups and gender. Average daily mortality was relatively raised around the 90th day of the year, coinciding with the peak of the temperature period (March-April). The study area has witnessed a couple of meningitis epidemics in recent years, mostly at a time when temperature is at its peak (March-April).	Ghana Meteorological Agency, Navrongo	

Study title & author(s)	Data	Data description	Data source	Data gaps
Rainfall Distribution in the Upper East Region of Ghana, 1976 – 2016. **Ampadu et al., 2019**	Monthly rainfall data from 1976-2016.	The data were used for the computation of monthly and annual values for descriptive statistical analysis such as mean (x), standard deviation (SD), and coefficient of variation. The study used a Microsoft Excel statistical tool to determine the descriptive statistics and the trend behaviour of rainfall.	Ghana Meteorological Agency, Navrongo	
Extreme Analysis of Maxima Rainfall in the Upper East Region of Ghana: A Case Study of Navrongo Municipality. **Angbing et al., 2020**	Yearly maximum rainfalls from January 1983 to December 2018 were used for the study.	Scatter plots of both the monthly total rainfall data and the yearly maximum rainfalls. Return periods with their corresponding return levels and profile likelihood confidence intervals were obtained. The analysis showed that the monthly maximum rainfall would continue to increase for a long period of time.	These data were obtained from the Navrongo Meteo-rological Agency	False assumption of stationarity of the process may lead to an underestimation of the probability of a disastrous extreme event.
Projected temperature increases over northern Ghana **Klutse et al., 2020**	Daily minimum and maximum temperature from 1980 to 2014 was used for the study.	The data were subjected to quality controls using RClimdex tool. Three regional climate models (RCMs), namely Swedish Meteorological and Hydrological Institute, CLMcom, and REMO from the CORDEX-Africa domain datasets emanating from five GCMs were selected and downscaled where the observed data was used for validation. The study shows that temperature has risen by almost a degree over the last century and is projected to accelerate over the next 50 years, resulting in an increase of further 1.5–3 °C of warming.	These data were obtained from the Navrongo Meteorological Agency	

Study title & author(s)	Data	Data description	Data source	Data gaps
Changing Weather and Climate in Northern Ghana: Comparison of Local Perceptions with Meteorological and Land Cover Data **Dickinson et al., 2017**	Monthly temperature and rainfall from 1983-2013.	The average monthly temperature anomalies and average monthly total precipitation were calculated for the entire 1979-2013 period, as well as the most recent 15-years, 10-years, 5-years, 3-years, 2-years, and 1-year. The Standardized Precipitation Index and the Standardized Precipitation-Evapotranspiration Index was used to assess the drought indices. The onset of the peak rainy season has shifted progressively later over the past decade, by up to a month, and the rainy season has been drier over the past 3-5 years compared to the past 10-35 years, mainly due to lower rainfall during peak months (June and July)	These data were obtained from Po weather station in Burkina Faso, 30 km north of Navrongo.	Integrating meteorological records and climate models with the local perspectives. Lack of long-term, reliable in situ meteorological records.

Appendix 2. Questionnaire Used for the Household Survey

This form is designed to collect data at community level in the Kassena Nankana municipality. The data will contribute to an ongoing climate vulnerability assessment. Responses will be used solely for this purpose.

Question	Options/Responses
Basic data on the respondent	
Location (latitude, longitude)	
Sex	Male [ ] Female [ ]
Age range	<30 [ ] 30 – 40 [ ] 40 – 50 [ ] 50-60 [ ] >60 [ ]
What is your educational level?	None [ ] Primary [ ] Secondary [ ] Tertiary [ ]
What is your primary occupation?	Agric. [ ] Civil service [ ] Business [ ] Unemployed [ ] Other [ ]
Exposure – Level to which respondents are exposed to climatic changes	
Which of the following changes have you observed in recent years?	Shifts in when the rains start and end Unusually high temperatures Increasing incidence of drought in the cropping season Increasing incidence of floods Increasing incidence of high intensity rainfall
To what extent are you exposed to the changes above? (Low [1]; High [5]	1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ]
Sensitivity - determine how sensitive respondents are to climatic changes	
What material is your house made of?	Mud/Brick [ ] Cement [ ] Mud/bricks & cement [ ] Other [ ]
Is your house in a flood prone area?	Yes [ ] No [ ] Other parts of the community [ ]
Has any part (or all) of your house collapsed due to heavy rain/flooding?	Yes [ ] No [ ] Other parts of the community [ ]
Is your farm or livestock pen in a flood prone area?	Yes [ ] No [ ] Other parts of the community [ ]
Adaptive Capacity - determine whether respondents have what it takes to adapt to climatic changes	
Do you have a mobile phone?	Yes, yam [ ] Yes, smartphone [ ] No [ ]
Which telecom company do you subscribe to?	MTN [ ] Airtel/Tigo [ ] Vodafone [ ] Other/None [ ]
Is there internet access in your area (house/vicinity)?	Yes [ ] No [ ]
14a. If yes, are you able to access the internet?	Yes [ ] No [ ] Sometimes [ ]
14b. If there is internet access in your area, but you don't connect to it, what could be the reason?	I don't have money to buy credit [ ] The service is very poor, so i waste my money [ ] I don't need it for anything [ ] My phone is not suitable for it [ ]
What is the average walking time from your house to the nearest market?	Less than 30 minutes [ ] 30 min to 1 hour [ ] More than 1 hour [ ]

What is the average walking time from your house to the nearest health facility?	Less than 30 minutes [ ] 30 min to 1 hour [ ] More than 1 hour [ ]
Do you have access to climate information (as a farmer)?	Yes [ ] No [ ] Sometimes [ ]
If yes, what is the nature of the service?	Radio stations [ ] Community radio [ ] Location-based [ ] Other [ ]
If yes, which company provides the climate information?	Esoko [ ] Ignitia [ ] Other [ ]
Do you have access to climate-tolerant seeds?	
Which of the following practices have you adopted in response to climate change impacts?	Agro-forestry [ ] Conservation agric. (e.g. no till) [ ] Use of organic fertlizers [ ] Other [ ]
Which of the following cropping systems do you use?	Crops only, mono-cropping [ ] Crops only, inter-cropping [ ] Livestock only [ ] Crop/livestock [ ] Crop/livestock [ ]
Do you have access to water for dry season cultivation?	Yes, every year [ ] Yes, some years [ ] No [ ]
If primary occupation is agriculture, which other income generating activity are you engaged in?	Trading [ ] Formal employment [ ] Migration to south [ ] Other [ ] None [ ]
Do you know about agricultural insurance?	Yes [ ] No [ ]
If yes, have you subscribed to any insurance product?	Yes [ ] No [ ] Interested but no money [ ]

Appendix 3. Detailed Responses From Household Survey

Table 13. Detailed responses from household survey

Questions	Responses (%)								
	Biu	Doba	Manyoro	Naaga	Navrongo	Yua	North-East	Sirigu	Telania
Basic data/ socio-economic information									
Male	86.7	82.4	63.2	61.9	59.3	66.7	50.0	61.9	63.2
Female	13.3	17.6	36.8	38.1	40.7	33.3	50.0	38.1	36.8
Age range (less than 40)	40.0	29.4	31.6	42.9	44.4	54.2	45.5	38.1	47.4
Age range (greater than 40)	60.0	70.6	68.4	57.1	55.6	45.8	54.5	61.9	52.6
Formal education (prim, sec, tertiary)	53.3	76.5	73.7	38.1	92.6	62.5	59.1	61.9	68.4
No formal education	46.7	23.5	26.3	61.9	7.4	37.5	40.9	38.1	31.6
Occupation (Agric)	80.0	64.7	52.6	90.5	37.0	79.2	59.1	76.2	73.7
Unemployed	20.0	17.6	15.8	4.8	7.4	20.8	18.2	19.0	26.3
Others (e.g. Civil service, Business etc)		17.6	31.6	4.8	55.6	0.0	22.7	4.8	0.0
Exposure to climatic changes									
Observed changes									
High temperatures	86.7	100.0	84.2	85.7	100.0	95.8	95.5	85.7	52.6
Increasing incidence of floods	93.3	100.0	36.8	81.0	51.9	91.7	31.8	23.8	100.0
Increasing incidence of high intensity rainfall	100.0	76.5	36.8	81.0	70.4	66.7	54.5	23.8	68.4
Increasing incidence of drought in the cropping season	53.3	94.1	89.5	76.2	85.2	91.7	77.3	85.7	84.2
Shifts in rainfall onset and cessation	53.3	76.5	100.0	61.9	100.0	87.5	95.5	95.2	100.0

Questions	Responses (%)								
	Biu	Doba	Manyoro	Naaga	Navrongo	Yua	North-East	Sirigu	Telania
Level of exposure									
Very high (5)	20.0	23.5	57.9	9.5	40.7	20.8	59.1	47.6	15.8
High (4)	53.3	47.1	21.1	33.3	29.6	33.3	18.2	23.8	26.3
Moderate (3)	13.3	35.3	10.5	28.6	25.9	29.2	13.6	14.3	26.3
Low (2)	13.3	23.5	10.5	14.3	3.7	16.7	9.1	9.5	15.8
Very low (2)	0.0	11.8	0.0	14.3	0.0	4.2	0.0	0.0	15.8
Sensitivity to climatic changes									
Type of house									
Mud/bricks	46.7	76.5	15.8	38.1	11.1	87.5	31.8	33.3	73.7
Mud/bricks and Cement	33.3	11.8	52.6	52.4	55.6	8.3	68.2	66.7	15.8
Cement	20.0	11.8	31.6	9.5	33.3	4.2	0.0	0.0	10.5
House prone to flooding									
Yes	53.3	52.9	47.4	47.6	25.9	54.2	59.1	52.4	15.8
No	46.7	47.1	52.6	52.4	74.1	45.8	40.9	47.6	84.2
other parts of the community	0.0	0.0				0.0	0.0		
House been destroyed by flooding									
Yes	93.3	76.5	36.8	61.9	29.6	54.2	54.5	52.4	21.1
No	6.7	23.5	63.2	38.1	70.4	45.8	45.5	47.6	78.9
Farm or livestock pen in flood prone area									
Yes	93.3	64.7	31.6	61.9	14.8	41.7	59.1	57.1	15.8
No	6.7	35.3	68.4	38.1	85.2	58.3	40.9	42.9	84.2

Questions	Responses (%)								
	Biu	**Doba**	**Manyoro**	**Naaga**	**Navrongo**	**Yua**	**North-East**	**Sirigu**	**Telania**
Adaptive Capacity									
Access to mobile phone									
Yes, smart phone	26.7	47.1	57.9	9.5	66.7	29.2	40.9	23.8	10.5
Yes, yam phone	66.7	41.2	42.1	76.2	25.9	62.5	50.0	71.4	73.7
No	6.7	11.8	0.0	14.3	7.4	8.3	54.5	4.8	15.8
Network company									
MTN	86.7	88.2	52.6	61.9	51.9	58.3	36.4	42.9	42.1
Vodafone/Airtel/Tigo	13.3	11.8	47.4	38.1	48.1	41.7	63.6	57.1	57.9
Availability of internet									
Yes	100.0	100.0	100.0	95.2	96.3	70.8	100.0	90.5	5.3
No	0.0	0.0	0.0	4.8	3.7	29.2	0.0	9.5	94.7
Accessibility of internet									
Yes	0.0	0.0	47.4	14.3	51.9	8.3	36.4	28.6	0.0
Sometimes	26.7	13.3	0.0	0.0	11.1	29.2	0.0	4.8	0.0
No	73.3	86.7	52.6	85.7	37.0	62.5	63.6	66.7	100.0
Distance to market by foot									
30 min to 1 hour	46.7	94.1	47.4	100.0	44.4	100.0	77.3	76.2	0.0
Less than 30 minutes	53.3	5.9	52.6	0.0	55.6		22.7	23.8	100.0
Distance to health facility by foot						**54.2**			
30 min to 1 hour	40.0	88.2	47.4	100.0	55.6	45.8	81.8	81.0	42.1
Less than 30 minutes	60.0	11.8	52.6	0.0	44.4		18.2	19.0	57.9

Questions	Responses (%)								
	Biu	Doba	Manyoro	Naaga	Navrongo	Yua	North-East	Sirigu	Telania
Access to climate information						**45.8**			
Yes	60.0	58.8	42.1	23.8	44.4	8.3	68.2	47.6	52.6
No	40.0	35.3	10.5	71.4	33.3	37.5	22.7	4.8	47.4
Sometimes		5.9	47.4	4.8	22.2		0.0	47.6	0.0
Nature of Service									
Radio station	0.0	58.8	42.1	4.8	33.3	8.3	18.2	19.0	5.3
Community radio, location based and radio station	0.0	11.8	52.6	76.2	37.0	37.5	50.0	33.3	84.2
Location based	60.0	29.4	0.0	4.8	0.0	12.5	0.0	0.0	0.0
Others	0.0	0.0	5.3	14.3	22.2	25.0	54.5	9.5	10.5
Source of climate information									
Esoko	0.0	0.0	5.3		0.0	4.2	4.5	9.5	0.0
Ignitia	0.0	5.9	21.1	9.5	7.4	4.2	22.7	14.3	10.5
Other	60.0	94.1	78.9	90.5	70.4	33.3	50.0	23.8	89.5
Access to climate-tolerant seeds									
Yes	100.0	17.6	10.5	23.8	18.5	12.5	22.7	4.8	0.0
No	0.0	52.9	89.5	76.2	77.8	12.5	95.5	95.2	5.3
Sometimes		29.4			3.7	33.3	4.5	0.0	94.7

Questions	Responses (%)								
	Biu	Doba	Manyoro	Naaga	Navrongo	Yua	North-East	Sirigu	Telania
Adaptation practices employed									
Agroforestry	0.0	0.0	0.0	4.8	3.7	0.0	0.0	0.0	0.0
Conservation agriculture (e.g., no till)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
use of organic fertilizer	26.7	5.9	31.6	14.3	48.1	4.2	40.9	23.8	5.3
More than one adaptation practice	73.3	94.1	68.4	81.0	48.1	95.8	59.1	76.2	94.7
Type of cropping system									
Crops only, mono-cropping	0.0	0.0	0.0						
Crops only, inter-cropping	20.0	5.9	15.8	0.0	11.1	0.0	9.1	19.0	5.3
Crop/livestock	80.0	94.1	78.9	100.0	85.2	100.0	86.4	81.0	94.7
Livestock only	0.0		5.3	0.0	0.0	0.0	4.5	0.0	0.0
Access to water for dry season cultivation									
Yes, every year	13.3	17.6	42.1	4.8	14.8	4.2	4.5	19.0	0.0
Yes, sometimes	0.0	29.4	0.0	0.0	11.1	0.0	4.5	14.3	5.3
No	86.7	52.9	47.4	95.2	74.1	95.8	95.5	95.2	94.7
Alternative livelihood									
Trading	13.3	11.8	26.3	9.5	22.2	12.5	27.3	23.8	5.3
Formal employment	0.0	5.9	5.3	0.0	18.5	0.0	0.0	0.0	0.0
Migration	13.3	0.0	10.5	0.0	0.0	16.7	18.2	19.0	0.0
None	46.7	29.4	52.6	42.9	37.0	37.5	50.0	57.1	47.4
Other	26.7	70.6	5.3	47.6	22.2	33.3	4.5	23.8	47.4

Questions	Responses (%)								
	Biu	Doba	Manyoro	Naaga	Navrongo	Yua	North-East	Sirigu	Telania
Knowledge about agricultural insurance									
Yes	46.7	47.1	42.1	42.9	29.6	20.8	4.5	14.3	0.0
No	53.3	52.9	57.9	57.1	70.4	79.2	95.5	85.7	100.0
Subscription to any insurance product									
Interested but no money	13.3	5.9	0.0	4.8	11.1	0.0	0.0	4.8	5.3
No	86.7	70.6	100.0	71.4	70.4	41.7	100.0	95.2	73.7
no response			0.0	23.8	18.5	58.3	0.0	0.0	21.1

Appendix 4. Stakeholders Represented at the Workshops

1. Navrongo Health Research Center
2. Kassena Nankana Municipal Assembly
3. National Disaster Management Organization
4. Ministry of Food and Agriculture
5. Ghana Education Service
6. Ghana Health Service
7. Statistical Services Department of Ghana
8. Ghana Meteorological Agency
9. Bolga Women's Group
10. Environmental Protection Agency
11. Traditional Authorities
12. Ghana National Fores Servoce
13. National Youth Authority
14. Ghana Federation Disability
15. CAMFED
16. JALLA
17. Tree Aid Ghana
18. Pure Radio
19. Department of Community Development
20. WEMATU Widows
21. Community Water and Sanitation
22. Irrigation Company of Upper Region (COUR-Tono
23. Forestry Commission
24. C. K. Tedam University of Technology and Applied Science
25. Ghana Irrigation Development Authority (GIDA)
26. Bolgatanga Technical University
27. Water Users Association, Organization for Indigenous Initiatives and Sustainability
28. Institute of Social Research and Development (ISRAD)
29. Input Dealers Association
30. Center for Social Mobilization and Sustainable Development (CENSODEV)
31. Research and Innovation for Sustainable Development (RISE)

32. Women in Agriculture Platform
33. Persons With Disability
34. Tono farmer cooperative group
35. Rice Seed growers
36. Peasant Farmers Association of Ghana

Kassena Nankana West District Assembly
KNWDA
PAGA

FREEDOM AND JUSTICE