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Climate Change Risk Assessment for Tamale Metropolitan Assembly

Enhancing Multi-Sector Planning and Capacity for Effective Adaptation in Ghana

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Table of Contents

List of Figures

List of Tables

Acronyms

AED	Average Expected Damage
AR	Assessment Report of the IPCC
CCKP	Climate Change Knowledge Portal
CCRA	Climate Change Risk Assessment
CCV	Climate Change Vulnerability
CRV	Climate Risk and Vulnerability
CIMA	Centro Internazionale in Monitoraggio Ambientale (*International Centre on Environmental Monitoring*)
CORDEX	Co-ordinated Regional Downscaling Experiment
CRIDF	Climate Resilient Infrastructure Development Facility
CRS	Catholic Relief Services
CSA	Climate-Smart Agriculture
CMIP	Climate Model Intercomparison Project
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FNC	Fourth National Convention
GCF	Green Climate Fund
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHS	The Cedi (currency)
GIS	Geographic Information System
GMet	Ghana Meteorological Agency
GSS	Ghana Statistical Service
GWCL	Ghana Water Company Limited
I&APs	Interested and Affected Parties
IC	Impact Chain
ICMP	Integrated Coastal Management Policy
ICZMS	Integrated Coastal Zone Management Strategy
IGF	Internally Generated Fund
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
KVIP	Twin-pit VIP Latrine
LE	Lower Extreme
MESTI	Ministry of Environment, Science, Technology and Innovation
MMDAs	Metropolitan, Municipal and District Assemblies

MoFA	Ministry of Food and Agriculture
MTDP	Medium Term Development Plan
NAP	National Adaptation Plan
NbS	Nature-based Solution
NDC	Nationally Determined Contributions
NMTDPF	National Medium Term Development Planning Framework
PRCPTOT	Total Annual Precipitation
PV	Photovoltaic
RCP	Representative Concentration Pathways
REDD+	'REDD' stands for 'Reducing emissions from deforestation and forest degradation in developing countries. The '+' stands for additional forest-related activities that protect the climate, namely sustainable management of forests and the conservation and enhancement of forest carbon stocks.
SOM	Self-Organising Map
SPEI	Standardised Precipitation and Evapotranspiration Index
SSP	Shared Socioeconomic Pathways
SU30	Hot days with a maximum above 30ºC
TaMA	Tamale Metropolitan Assembly
TG	Daily Mean Temperature
TNC	The Nature Conservancy
TXx	Maximum temperature
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UE	Upper Extreme
WACA	West Africa Coastal Areas Management Programme
WGII	Working Group II of the IPCC
WTP	Water Treatment Plant
WWF	World Wide Fund For Nature

Executive Summary

INTRODUCTION

The Government of Ghana, through the Environmental Protection Agency (EPA), under the auspices of the Ministry of Environment, Science, Technology, and Innovation (MESTI), has obtained a grant from the Green Climate Fund (GCF) for a three-year project to build capacity to advance the National Adaptation Plan (NAP) process in Ghana. The United Nations Environment Programme (UNEP) is the Delivery Partner, supporting and overseeing the project implementation.

The project entitled **"Enhancing multi-sector planning and capacity for effective adaptation in Ghana"** is being implemented by a small project team headed by a National Co-ordinator.

To support the objectives of the NAP program, this Project has been initiated to support Producing Climate Change Scenarios and Risk Assessments for Ghana, based on best available techniques and data that can be used as the basis for national and sub-national climate change adaptation planning.

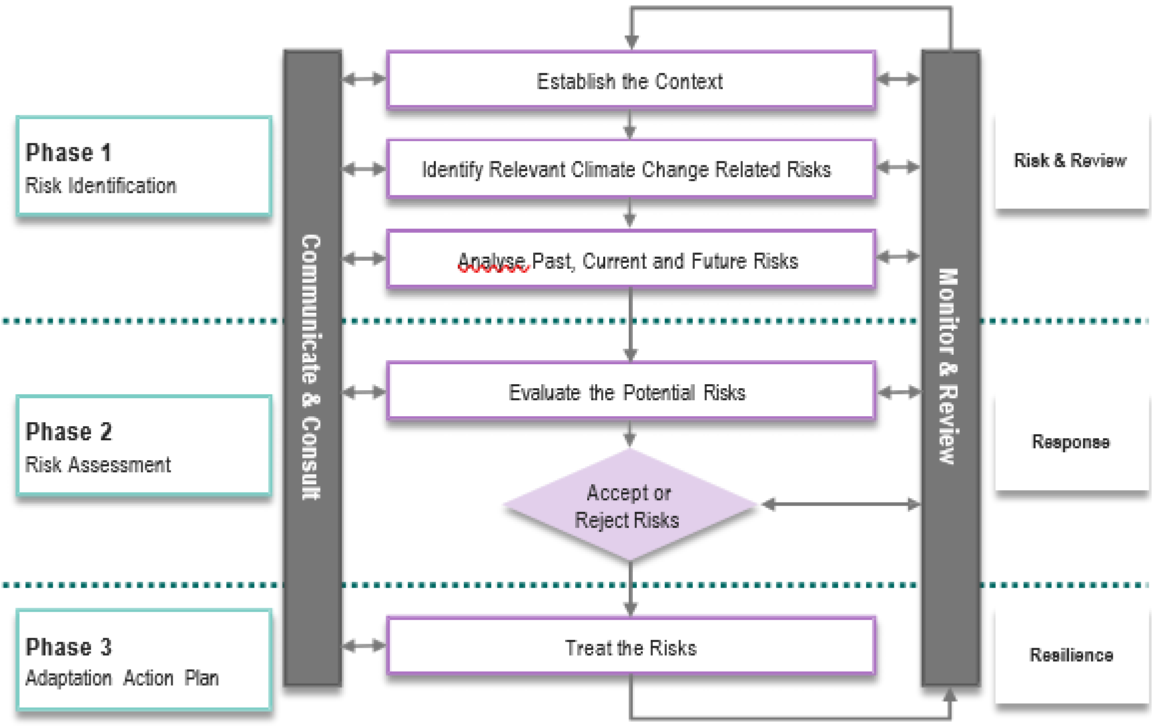
The specific activities to be undertaken under this Study are as follows:

- Task 1: Develop a methodology for producing national climate change scenarios
- Task 2: Develop downscaled/area-based climate change projections for Ghana
- Task 3 & 4: Develop national and sub-national level climate risk assessments for two MMDAs
- Task 5: Summary for Policy-Makers, Training and Capacity Building

This report is the deliverable from Task 3.4 and provides the CCRA for **Tamale Metropolitan Assembly (TaMA), for up to four first-order (biophysical) risk domains**, and **up to three second-order (economic sectors) risk domains**, developed in collaboration with national stakeholders in Ghana.

The approach undertaken in determining the CCRA for TaMA follows the general risk assessment process as shown in Figure e1 below.

Figure e1 I General overview of the risk assessment process

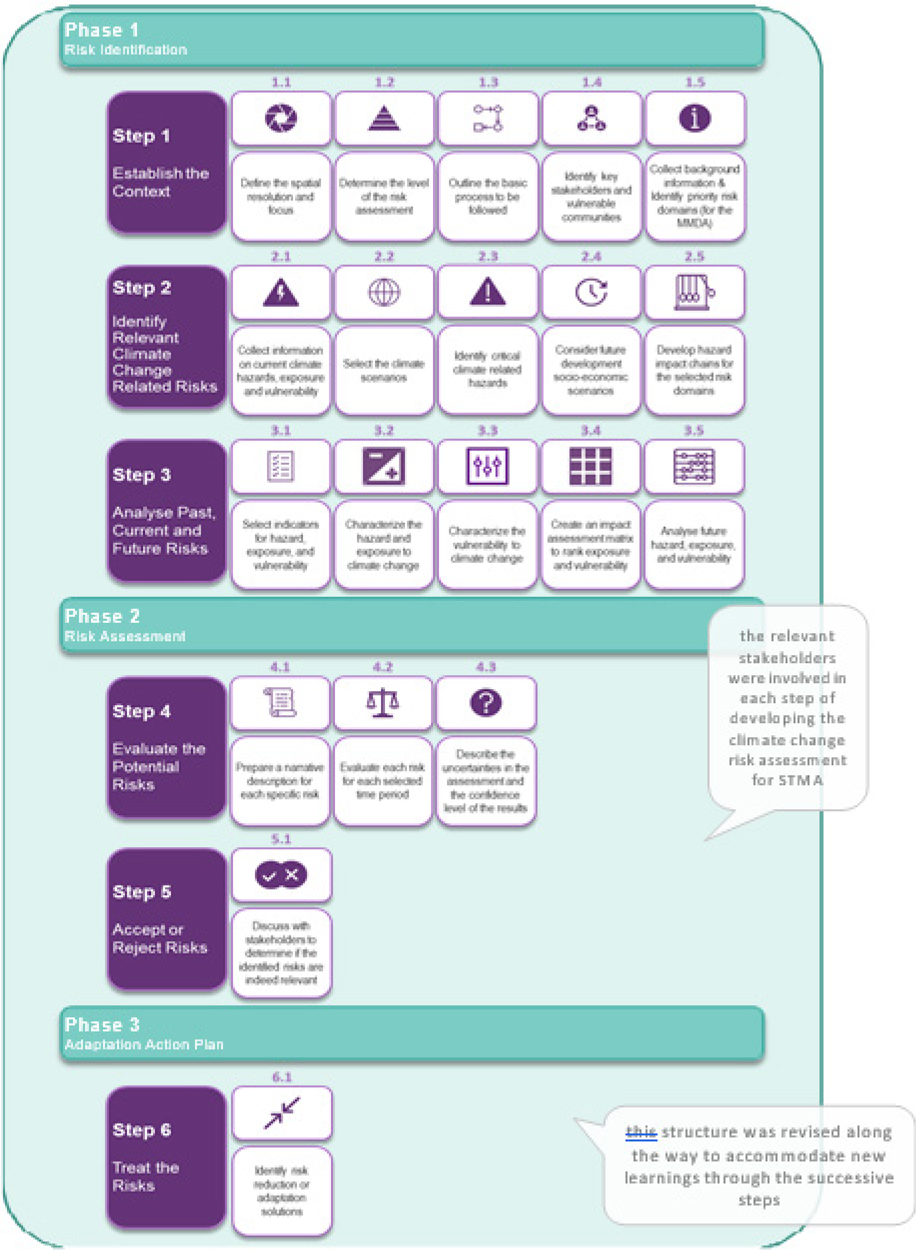


Source: Adapted from (Norman, et al., 2014)

The steps covered under this assignment relate to Phase 1 (Risk Identification) and Phase 2 (Risk Assessment).

The figure below summarises the specific steps, and timeline, followed for undertaking the CCRA

Figure e2 I Process followed during the CCRA

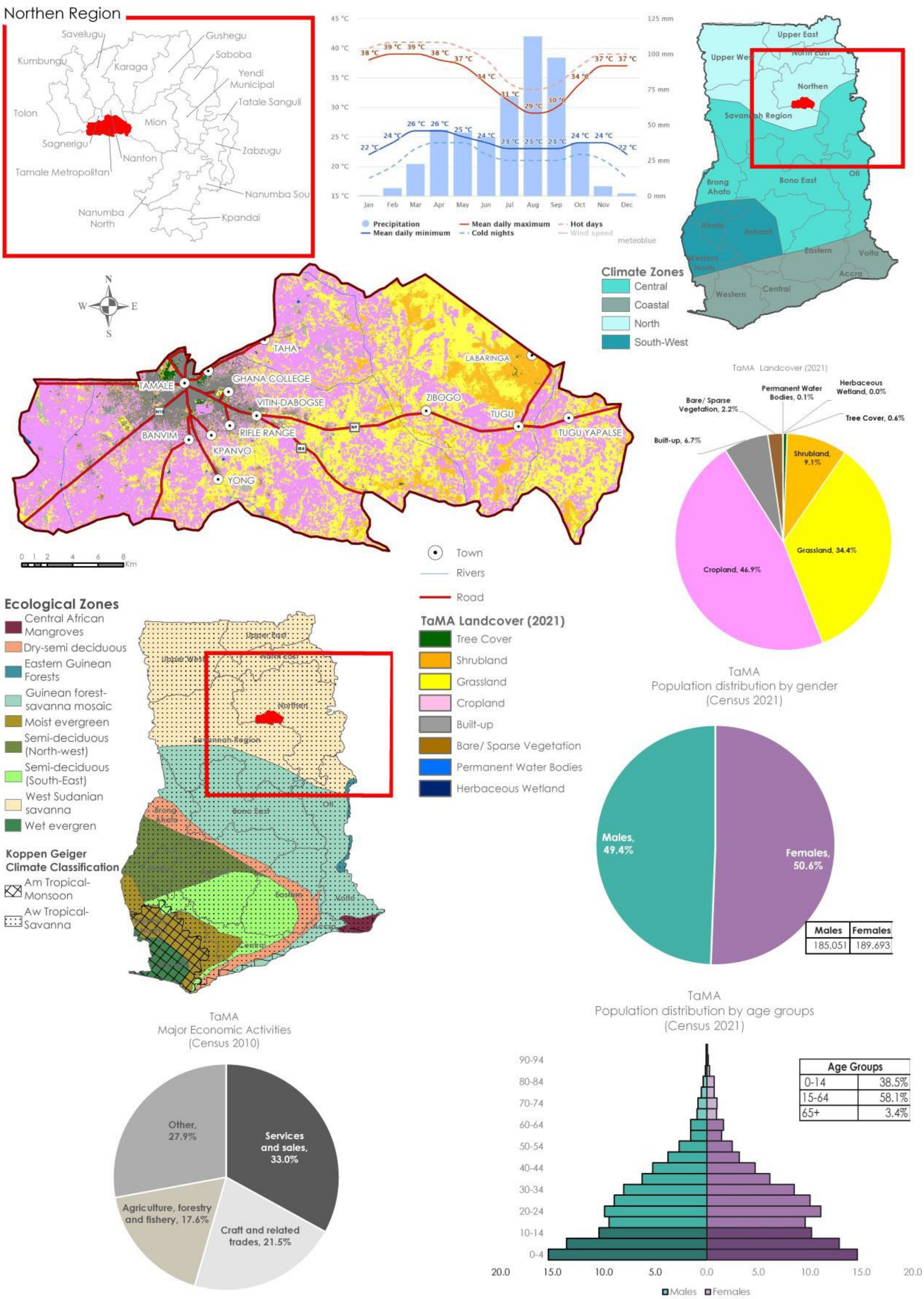


In order to inform the development of the climate risk assessment for TaMA, the project team undertook a site excursion from 28 November until 9 December 2022. The purpose of this trip was to engage with key stakeholders in TaMA, as well as at a national level to collect data and anecdotal evidence to better understand the climate change risks and their impacts, and the adaptive capacity of local communities.

Following the engagement with local stakeholders in TaMA, a second two-day workshop was held in Accra with national level stakeholders and government representatives.

The figure below provides an overview of Tamale Metropolitan Assembly.

Figure 1 Overview of Tamale Metropolitan Assembly



OBSERVED CLIMATE AND TRENDS IN GHANA AND TAMALE

Ghana's generally tropical climate is strongly influenced by the West African monsoon winds, which vary slightly along with the country's varied topography. With most of the rain falling in intense storms of short duration, the country is vulnerable to extreme events such as heavy rainfall (with on average 44 mm per day) resulting in heavy runoff and erosion, especially at the beginning of the rainy season. At the same time, the long dry season in the north has led to serious droughts in the region (Ministry of Foreign Affairs of the Netherlands, 2019).

Ghana's high degree of vulnerability to climate change poses a threat to growth and development.

The mean annual temperature in Tamale is currently just below 29°C but has risen by approximately 1°C since the late 1970s. Since 2000, the mean annual and decadal temperatures have consistently been more than 28.4°C. Precipitation in Tamale, and the Northern Region, experienced a high degree of interannual and interdecadal variability. However, since the 1960s, an overall reduction in cumulative rainfall per decade was observed. Rainfall trends have tended to decline in the middle of the country over the past few decades, with more intense rainfall events occurring in both the north and south of the country, indicating an increase in the intensity of rainfall events and the possibility of increased dry spell durations (The World Bank Group, 2021a). Rainfall continues to be highly variable for Tamale, but there does not appear to be a continuation of the downward trend in mean annual precipitation (MAP) that was experienced during the 1980s and 1990s, suggesting that climate change may in fact be contributing to a general increase in MAP, rather than a further reduction in MAP.

CLIMATE CHANGE VULNERABILITIES FOR TaMA

Current vulnerability

Tamale is already experiencing significant challenges due to population growth, failing infrastructure, and climate change. With a rapidly growing population, limited water resources, and a fragile economy largely dependent on farming and trading, the City's vulnerability, exposure, and adaptive capacity to climate change, are crucial factors to consider in building the resilience of the people of Tamale.

Tamale's vulnerability to climate change is primarily due to its geographic location and socioeconomic factors. The City is situated in the Northern Region of Ghana within the Guinea Savannah belt, known for its semi-arid climate and seasonal rainfall patterns. The majority of the population depends on farming and trading for their livelihoods, rendering them particularly susceptible to the impacts of climate change on agriculture and food security. Furthermore, the Northern Region is one of Ghana's three poorest regions, exacerbating people's vulnerability to climate risks. The City's economy needs to be developed and diversified further to enable the necessary investments in climate adaptation measures.

Tamale is exposed to multiple climate change-related hazards, including Harmattan winds during the dry season (UN Habitat, 2009). These winds contribute to soil erosion and decreased fertility, negatively affecting agriculture. Limited water resources, with few seasonal rivers, exacerbate the local water supply challenges, threatening farmers' and traders' livelihoods, as well as water security for households. The main water supply for Tamale is from the White Volta River which is impacted by the activity of upstream users, poor catchment management, and sand mining. These combine to increase the vulnerability of Tamale to the potential impacts of climate change on water security. Current initiatives such as improvements to the water abstraction point and water treatment plant, as well as the potential for establishing a Tamale Water Fund, will help in reducing this vulnerability.

During the rainy season, flooding caused by heavy precipitation and water releases from the upstream Bagre Dam, poses a problem. This flooding damages infrastructure and degrades water quality due to sediment. Catchment degradation and sand mining in the region further heighten the vulnerability of Tamale communities. Climate change is anticipated to worsen these issues, with predictions of rising temperatures, unpredictable rainfall, and extended dry seasons. Flooding risk is increased in Tamale due to a lack of maintenance of the stormwater system, unplanned development and deforestation.

The City's rapid population growth places significant pressure on the limited natural resources, such as water and arable land. As the population increases, farmers are being pushed into less favourable locations to continue production, including flood plains and along public drains where wastewater is used for irrigation. To prevent food security from deteriorating, there is a need to protect urban and peri-urban agricultural lands by mapping and preserving the high-potential production areas (Kuusaana & Eledi, 2015). Furthermore, the region's relative poverty and limited infrastructure hinder the development and implementation of effective adaptation strategies. The City needs to strengthen the capacity of the existing social systems and institutions, both governmental and NGOs, to facilitate collective action to address climate change.

The level of awareness about climate change risks and adaptation options also needs to be improved to enhance adaptive capacity and to enable traditional systems to support the communities. As noted previously, TaMA has a reasonably high level of adaptive capacity.

Future vulnerability

A parallel study has considered the development of local-level socioeconomic development scenarios that can assist with evaluating the potential for future climate change risk and vulnerability under different future scenarios. These scenarios were developed based on four of the global Shared Socioeconomic Pathways (SSPs), as developed by O'Neill et al. (2015), namely: *Sustainability – Taking the Green Road*, *Fossil-fuelled Development – Taking the Highway, Inequality – A Road Divided, and Regional Rivalry – A Rocky Road.*

The four selected SSPs have been applied in terms of identified key drivers of change at the national level, for three key sectors (agriculture, energy, and health), and at the local level for TaMA. These have been assessed in terms of the potential impact that these alternative development scenarios will have on climate change vulnerability.

Under the **Sustainability future scenario,** overall climate change vulnerability is reduced by means of investments in ecological infrastructure and pro-active urban planning. Improvements in agricultural practices and successful water resources development through the One Village One Dam project have also reduced the sensitivity to drought and any potential impact of climate change on rainfall availability. In addition, the efforts made to reduce deforestation and to reduce plastic pollution have reduced the potential risks associated with any possible increase in flooding risk. This is also as a result of improved collaboration between local government and national government around protecting critical infrastructure, and the increased provision of basic services and improved health care facilities.

Under the **Fossil-fuel development scenario**, the potential impacts of climate change will be greater, but the sensitivity and adaptive capacity could potentially be strengthened if these developments result in a stronger local economy, and if these benefits are used to reduce the vulnerability to climate change. This could include for example investing in improved water supply infrastructure and stormwater management systems, and providing social safety nets for the most vulnerable. If these pro-active investments are not made, there is likely to be an increase in inequality, which will result in and overall increase in the vulnerability to climate change, as well as other risk factors.

Under the **Inequality - Road Divided scenario**, the local government of Tamale receives limited support from the central government, and therefore have to solve most of their problems on their own and with limited resources. This could lead to innovative solutions and reduced climate change vulnerability, but it is more likely to drive inequality, with those who have the means being able to adapt to increase climate-related risks by installing their own water supply systems or flood protection, and with the vast majority of the population without the means to do so, becoming even more sensitive and vulnerable to climate impacts.

Under the **Regional Rivalry – Rocky Road scenario** the world is characterized by competition, and a weakening of the structures for international co-operation. There is limited inflow of aid in all forms, and this reduces the availability of funds to undertake relevant projects. As a result, the vegetation of Tamale and its environs will come under threat due to the lack of commitment to maintain such reserves. This increased regional competition will increase the pressure on natural resources, resulting in further deforestation and catchment degradation, and increase impacts due to sand mining. These will result in a significant increase in the sensitivity and potential impact of any increases in climate-related risks. At the regional level, a lack of collaboration with upstream states, will make Ghana far more vulnerable to the impacts of upstream developments on water supply, and could also result in increased migration.

CLIMATE CHANGE RISK ASSESSMENT RESULTS FOR TaMA

Based on the review of future climate scenarios and the engagement with key stakeholders, impact chain diagrams were developed for the priority hazards and risks identified above. These were then used to evaluate both the current and future level of risk as a function of hazard, exposure and adaptive capacity. For each of these priority risk domains, potential adaptation options were considered, and their potential impact on reducing the overall climate-related risks were determined as a residual risk.

Following the consideration of potential adaptation options, the critical systems with the highest residual risk, and therefore considered to be important for prioritising adaption responses, were:

- Potential flood risk to the water treatment plant (and other critical infrastructure), as well as the impacts of upstream catchment degradation and sand mining on water quality.
- Overall impact on water resource availability and water supply infrastructure.
- Damage to road infrastructure and disruptions due to increased urban flooding risk.
- Impact on health systems, including damage to hospitals and access to health facilities.
- Impact on crop productivity and livestock health.
- Impact on fisheries (rivers) due to more variable flows and higher sediment loads.

POTENTIAL ADAPTATION OPTIONS AND RECOMMENDATIONS FOR TaMA

Below is a non-exhaustive list of adaptation options from the various previous studies and policy documents consulted by the Project Team, which could improve the residual risk level for TaMA:

- **General Adaptation Response Priority Projects for critical infrastructure**
  - **Energy Sector:**
    - Resilient and green energy access in drought-prone districts
    - Capacity development and regulatory frameworks to support local renewable energy generation, including solar energy, to enhance resilience of remote, vulnerable communities
    - Update energy sector design standards to incorporate climate adaptation risk
  - **Water Sector:**
    - Water supply resilience through regional harvesting and storage solutions

- Climate adaptation alignment across water ministries, and planning mechanisms to ensure integrated water resource management
- Proactive risk-informed asset management

– **Transport Sector:**

- Supporting resilient design and construction of roads through research, capacity building, and the creation of a design manual
- Climate risk-informed asset management system and operations and maintenance practices for roads
- Airport flood resilience through elevation of runways and other vulnerable components
- Bridges and underpasses to ensure community access to services

– **Agricultural Sector:**

- Ensure affordability and financial sustainability of crop and livestock insurance products[1], such as weather index insurance (this measure will mostly increase resilience of vulnerable communities to climate-related risks, in addition to increasing investments that can raise agricultural productivity)
- Invest in improved post-harvest management systems
- Improve water management, and explore potential for irrigation upscaling, including by upscaling the use of solar irrigation
- Facilitate setting up of rainwater harvesting structures for small-scale irrigation by building on existing maps, to identify potential areas for groundwater development for small-scale irrigation
- Increase investment in local breeding of improved crop varieties and improve dissemination of higher quality/robust seeds
- Improve land and soil management strategies, including integrated soil fertility management, to reduce erosion and degradation of soils

– **Urban planning:**

- Development of an overall drainage plan that is consistent with the Greater Tamale Structure Plan and that identifies the low-lying areas and the locations of outfalls and main drains, and considers future population and land use
- Develop, broadcast, and enforce zoning guidelines or other local regulations, to ensure encroachment on flood prone areas is avoided

– **Cross-sectoral:**

- Upstream afforestation of the Volta River reservoir to build resilience to flood and drought
- Centralised climate-risk data management system
- Mainstream resilience through climate risk assessments and EPA permitting process and strengthen enforcement for all infrastructure projects

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1 New low-cost index-based crop and livestock insurance packages are becoming increasingly available. An example: Ghana's farmers arm against freak weather with crop insurance I PreventionWeb

- Gender mainstreaming in adaptation planning, implementation and management
- Prioritise nature-based solutions in planning, design and operation of infrastructure

1 Introduction

1.1 Study Aims and Objectives

The Government of Ghana, through the Environmental Protection Agency (EPA), under the auspices of the Ministry of Environment, Science, Technology, and Innovation (MESTI), has successfully obtained a grant from the Green Climate Fund (GCF) for a three-year project to build capacity to advance National Adaptation Plan (NAP) process in Ghana. The United Nations Environment Programme (UNEP) is the Delivery Partner, supporting and overseeing the project implementation.

The project entitled **"Enhancing multi-sector planning and capacity for effective adaptation in Ghana"** is being implemented by a small project team headed by a National Co-ordinator.

The NAP project seeks to support multi-sectoral, medium- to long-term adaptation planning and budgeting in Ghana, and promote the integration of climate change adaptation issues into development planning processes and policies. Systems for developing and sharing climate risk and vulnerability information will be reinforced, and sustainable financing mechanisms for climate change adaptation initiatives are set to be developed.

To support the objectives of the NAP program, this Project has been initiated to support Producing Climate Change Scenarios and Risk Assessments for Ghana, based on best available techniques and data that can be used as the basis for national and sub-national climate change adaptation planning.

Central to the preparation of effective climate change risk assessments (CCRAs) is the ability to understand the science behind the projections, manage the inherent uncertainty associated with them, analyse them using a variety of techniques, and then communicate the impact risks clearly and concisely in an actionable format for decision-makers and for a wider audience of non-technical stakeholders and users.

This work is intended to support several national initiatives in Ghana, including the updated NAP. However, it must also be able to underpin the climate rationales necessary to secure international climate finance. This requires an understanding of the past and current climate impacts, the potential impact of future climate, with and without climate change, and the disaggregation of other changes that are occurring in the area covered by the risk assessment, so that the impact of climate change can be isolated, analysed and presented in the form of a robust and clear climate risk narrative for Ghana.

1.2 Document Purpose

The specific activities to be undertaken under this work are as follows:

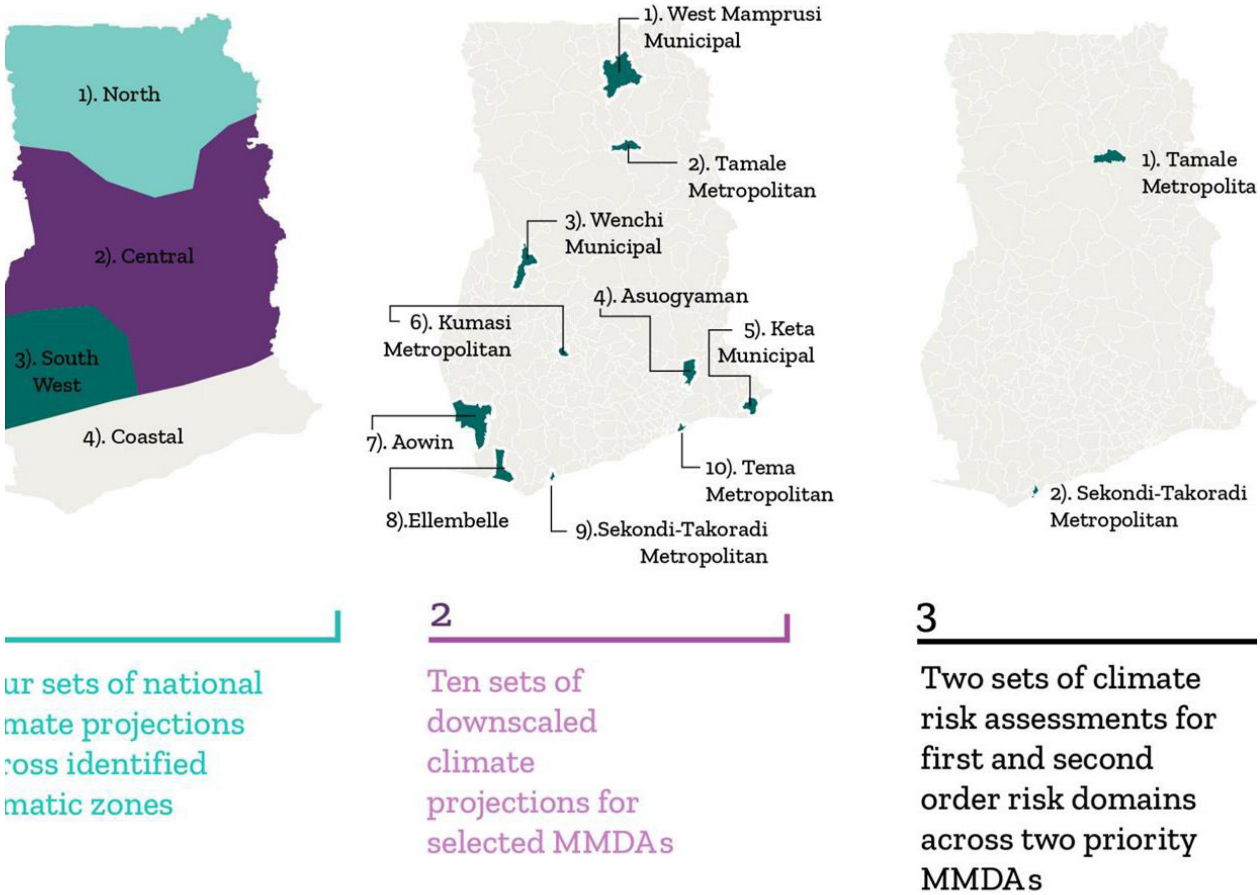
- Task 1: Develop a methodology for producing national climate change scenarios
- Task 2: Develop downscaled/area-based climate change projections for Ghana
- Task 3 & 4: Develop national and sub-national level climate risk assessments for two MMDAs
- Task 5: Produce a summary for Policy-Makers, Training and Capacity Building

The identification of priority MMDAs followed a selection process developed in consultation with representatives of the Government of Ghana, with technical support from the UNEP (Figure 2).

This report is the deliverable from Task 3.4 and provides the CCRA for **Tamale Metropolitan Assembly (TaMA),** for up to **four first-order (biophysical) risk domains**, and **up to three second-order (economic sectors) risk domains**, developed in collaboration with national stakeholders in Ghana.

The methodology used to assess the climate change risk for TaMA follows the approach developed under Task 3.3, summarized in Section 2 of this Report. The climate risk assessment results presented here are based on a detailed analysis of possible future climate change scenarios for Ghana as well as for the individual MMDAs, resulting from Task 2 and presented in a separate technical report.

Figure 2 I Spatial scale of key deliverables

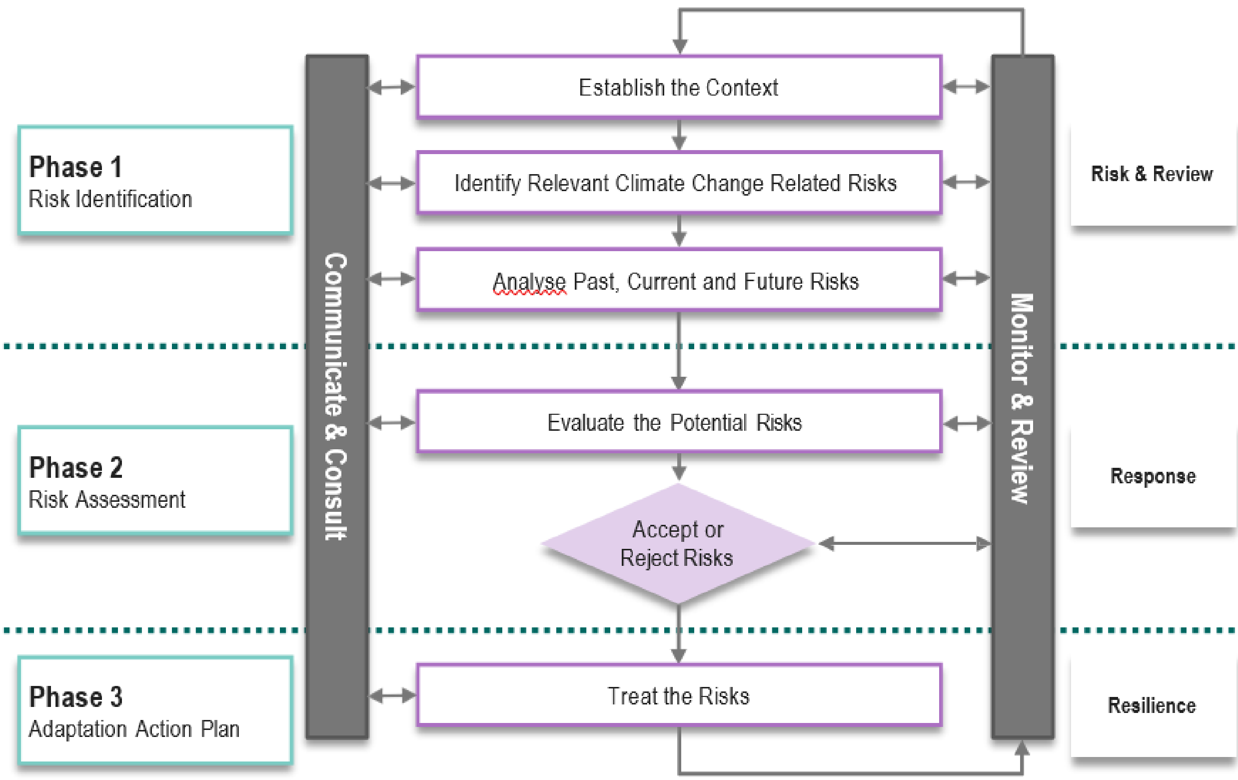


2

Approach and Methodology

The approach undertaken in determining the Climate Change Risk Assessment (CCRA) for TaMA follows the general risk assessment process as shown in Figure 3 below.

Figure 3 I General overview of the risk assessment process



Source: Adapted from (Norman, et al., 2014)

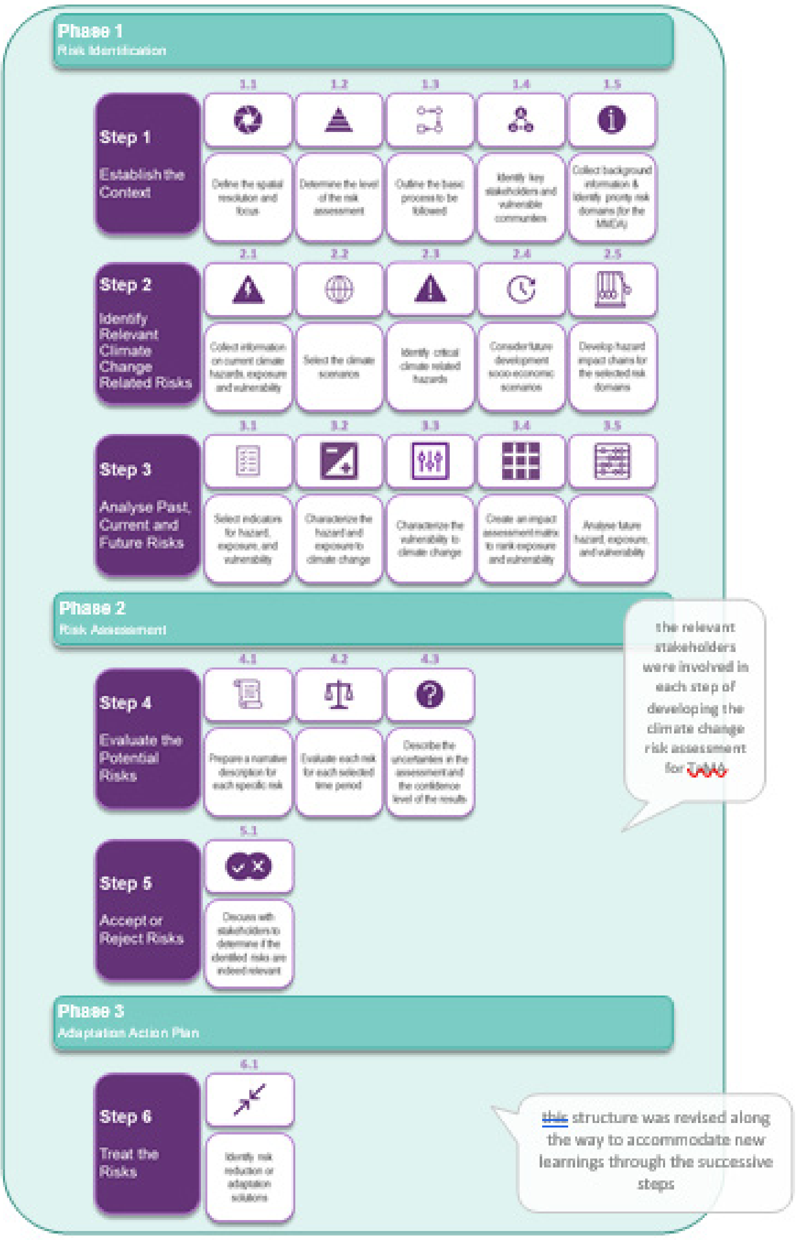
The steps covered under this assignment relate to Phase 1 (Risk Identification) and Phase 2 (Risk Assessment). The results of the risk assessment can then be used to inform adaptation planning as a combination of a 'top down" and "bottom up" approach to evaluating climate change related risks.

Climate change risk assessment should be a participatory process, sensitive to issues of gender, youth and the possible presence of vulnerable groups. To this end, the involvement and commitment in the assessment process of all interested and affected parties (I&APs), including members of local communities, should be integrated throughout the risk assessment process and phases. The level of engagement will vary depending on the aims and objectives of the study, the relevant scope and the process to be followed. The stakeholder engagement process is described in Section 3.5 of this Report.

To ensure that the risk identification process is grounded in the local context and considers the specific needs and concerns of the communities within the two selected MMDAs (i.e. Tamale and Sekondi-Takoradi), the Project Team undertook a site excursion from 28 November 2022 to 9 December 2022. The purpose of this visit was to engage with selected key stakeholders in each MMDA, to collect data and anecdotal evidence to better understand the climate change risks and their impacts, and the adaptive capacity of local communities. The basic approach to identifying the climate risk involved identifying the relevant key risk domains and then determining the relevant climate hazards and level of exposure and sensitivity, as well as the potential for adaptive capacity pertinent to that specific risk domain or sub-sector.

Figure 4 summarises the specific steps, and timeline, followed for undertaking the Climate Change Risk Assessment for TaMA, the results of which are presented in this Report.

Figure 4 I Process followed during the CCRA



3

Background and Context

3.1 Defining Climate Change Risk and Vulnerability

According to the Intergovernmental Panel on Climate Change (IPCC), climate risk results from the interaction of hazard, exposure and vulnerability. In the IPCC online glossary[2], the revised definition of **Risk** [used in the Special Report on Climate Change and Land and Special Report on the Ocean and Cryosphere in a Changing Climate – SRCCL (09/2019)] is as follows , and is also presented graphically in Figure 5 (from IPCC, 2014)

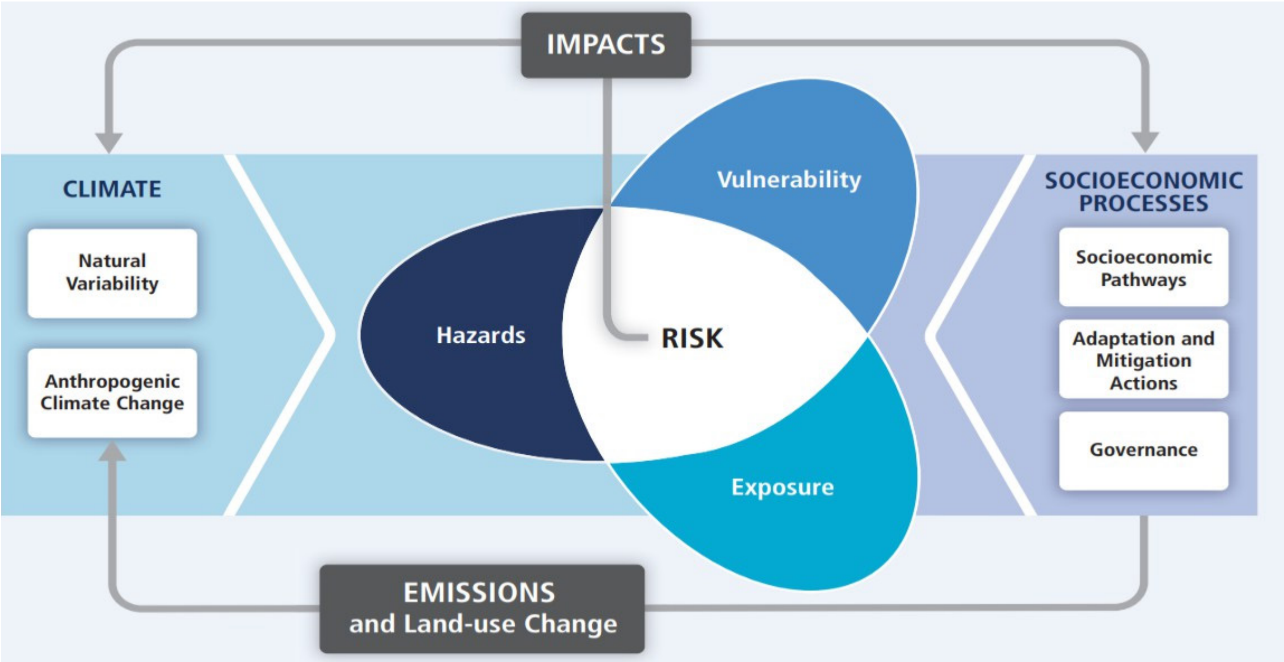
Climate Change Risk is defined as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.

- In the context of climate change impacts, **risks** result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. **Hazards, exposure,** and **vulnerability** may each be subject to uncertainty in terms of **magnitude** and **likelihood of occurrence**, and each may change over time and space due to **socioeconomic changes** and **human decision-making**.
- In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals. Risks can arise for example from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.

Source: IPCC online glossary (https://apps.ipcc.ch/glossary/)

2 https://apps.ipcc.ch/glossary/

Figure 5 l Risk assessment framework for evaluating climate change risks (IPCC, 2015)



Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes, including adaptation and mitigation (right), are drivers of hazards, exposure and vulnerability.

Source: IPCC's Fifth Assessment Report (WGII AR5) (Field, et al., 2014)

The following definitions of Hazard, Exposure, Sensitivity and Adaptive Capacity are used:

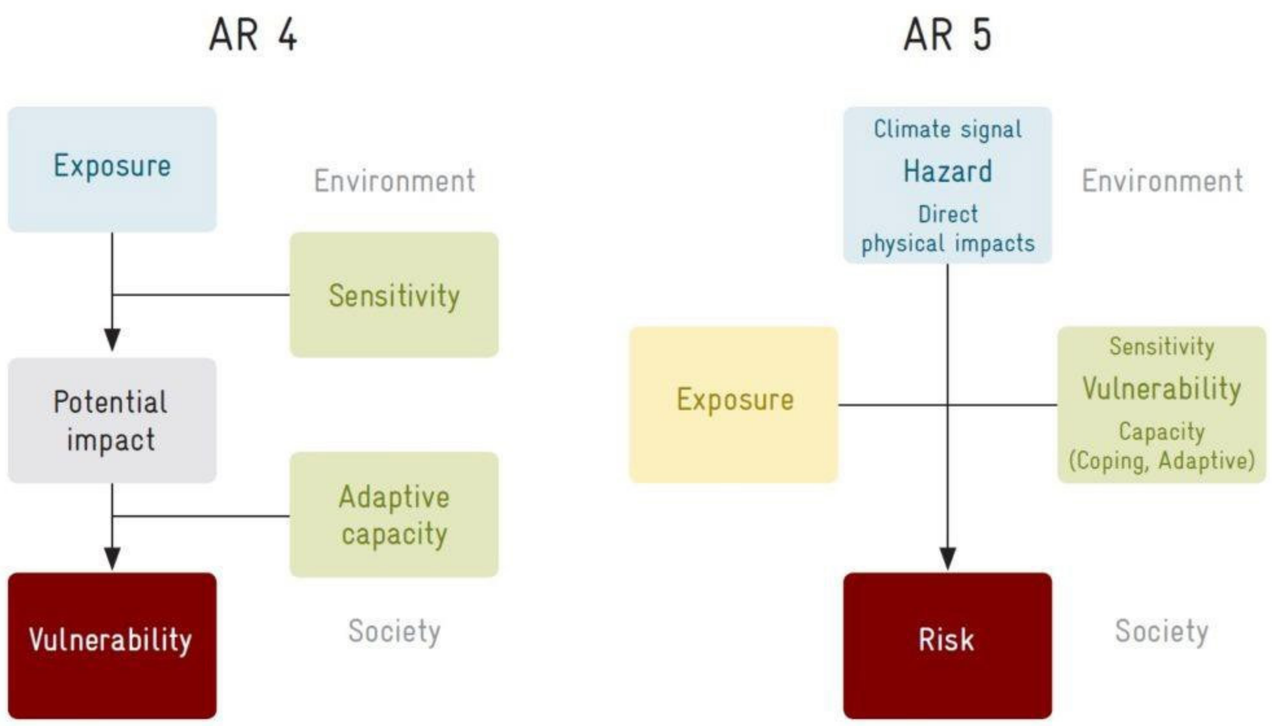
- **Hazard** is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- **Exposure** entails 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.
- **Vulnerability** deals with the propensity or predisposition to be adversely affected. Vulnerability 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 by, or responsive to a hazard. In other words, sensitivity captures the potential of a system to be impacted by a hazard. Sometimes sensitivity is determined by the criticality of the service that the system provides. For example, a community uses a road located close to the low-lying area of the coast as its main access to a major hospital. In the past, this road has been inundated during a storm event making access to the hospital difficult. Because the hospital provides such an essential service, this community should be considered more sensitive to coastal inundation event.
- **Adaptive Capacity** is the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Source: IPCC online glossary (https://apps.ipcc.ch/glossary/)

In summary, a **climate risk** (e.g., drought damage in agriculture) results from interactions between **climate-related hazards** (e.g., the frequency and intensity of droughts) with **exposure** (e.g., agricultural land) and **vulnerability** (e.g., drought resistance of crops, presence or absence of irrigation) of natural and human systems.

It is important to note the change in the definitions used for determining vulnerability and risk, as discussed above, between the fourth (AR4) and fifth (AR5) assessment reports, as shown in Figure 6.

Figure 6 l Change in the conceptual approach to climate change risk assessments



Source: (Zebisch, et al., 2021)

3.2 Climate Change Policy and Context

Ghana's Environmental Protection Agency (EPA) is technically responsible for coordinating the country's national climate change strategy. Strategy leadership is conducted in partnership with the Ministry of Environment, Science, Technology and Innovation (MESTI). Climate change is recognized as a cross-cutting issue in Ghana, and policies and implementation include cross-sector efforts and co-ordination including the National Development Planning, Forestry, and Energy Commissions, and the

Ministries of food and Agriculture, Lands and Natural Resources, and Power.

In recent decades, Ghana has made significant progress in the field of climate change by establishing suitable policy conditions to enable the country to increase its efforts in tangible climate actions:

- Ghana became a member of the United Nations Framework Convention on Climate Change (UNFCCC) after ratification in September 1995
- The Kyoto Protocol ratified in May 2003
- National Climate Change Policy (2015-2020)
- Climate Change Adaptation Strategy (2010-2020) published in 2012
- Low carbon development strategy published in 2015
- The Paris Agreement ratified in September 2016
- Nationally Determined Contributions (NDC) (2020-2030) updated under the Paris Agreement (2016)
- Ghana's National Adaptation Plan Framework published in 2018, to provide an overall framework to guide the country in developing, co-ordinating, and implementing its NAP process.

- Fourth National Communication for the UNFCCC published in 2020

Despite the progress made in recent years, Ghana must continue to strengthen local capacities and planning instruments at the national and sub-national levels to address medium and long-term adaptation needs. In this context, the project **"Enhancing multi-sector planning and capacity for effective adaptation in Ghana"** led by the Environmental Protection Agency (EPA), on behalf of the Ministry of Science, Environment, Technology, and Innovation (MESTI).

Implementation of climate change activities has been relatively slow. However, the Ghanaian Government continues to make concerted efforts to integrate climate change objectives and priorities into sector-specific development plans in agriculture, water, transportation and energy, to mainstream climate change strategies. Ghana submitted its Fourth National Communication to the UNFCCC in 2020, its Second Biennial Update Report in 2018, and its NDC to the UNFCCC in 2016 under the Paris Agreement and subsequently updated the NDC in 2021. These documents, in conjunction with its National Climate Change Adaptation Strategy (2010), provide the guidance and platform to integrate responsible environmental management with climate change adaptation strategies, in line with the country's social and economic development targets. These strategies focus on the preparation and strengthening of institutional frameworks for improved management of climate change effects, and to make available the necessary resources to support strategic adaptation activities, as well as to advance low emission and climate-resilient development (The World Bank Group, 2021).

This CCRA for TaMA was also informed by the following national and sub-national level risk assessments undertaken in the last decade, verifying the results based on the updated climate scenarios and downscaling the data to the TaMA level where possible:

- CIG Ghana: Flood risk mapping and modelling report, 2022
- Development of a Business Case for the Tamale Water Fund, 2022
- Ghana: Roadmap for resilient infrastructure in a changing climate, 2022
- Climate Risk Profile: Ghana (The World Bank Group), 2021
- Climate Change Profile: Ghana (Ministry of Foreign Affairs of the Netherlands), 2019
- Ghana Disaster Risk Profile (UNDRR and CIMA), 2019
- Climate Risk Analysis for Identifying and Weighing Adaptation Strategies in Ghana's Agricultural Sector, 2019
- Climate Change Risk Profile – Ghana (Fact Sheet), 2017
- Ghana agricultural sector risk assessment, 2016
- Climate and health country profile- 2015 Ghana, 2015
- UNDP climate change country profiles: Ghana, 2012

3.3 National Level Risk and Vulnerability Assessment

As part of the Fourth National Communication (FNC), a national level climate vulnerability assessment was undertaken to determine the overall climate vulnerability for each of the 216 MMDAs.

The national level vulnerability assessment undertaken for the FNC was based on the original AR4 definition of climate change vulnerability (CCV) as: (Exposure x Sensitivity) – Adaptive Capacity.

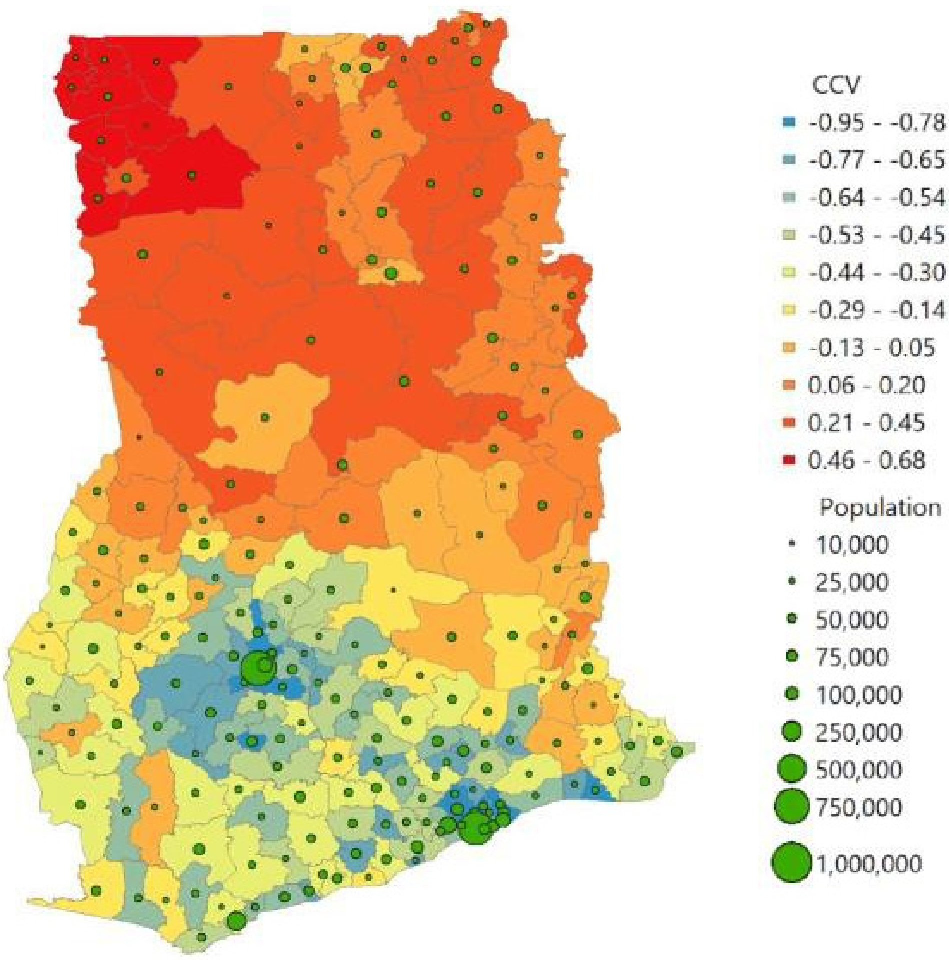
Data was collected at the MMDA level for a range of representative variables and used to determine a CCV score for each MMDA, based on the relative ranking for each of the representative variables.

For this analysis, exposure to climate change risk was determined based on the relative change in temperature and precipitation derived from an ensemble of 10 general circulation models, downscaled using five regional climate models and for four sub-parameters, including percentage change by: i) 2060 under RCP2.6; ii) 2060 under RCP8.5; iii) 2080 under RCP2.6; and iv) 2080 under RCP8.5.

Sensitivity was determined based on the population employed in the agricultural sector, and adaptive capacity was based on the results from the District League Table, which incorporates measures of education, sanitation, rural water availability, health, security, and governance effectiveness, to assess development across Ghana's 2016 districts and several other development-related variables. It is important to note that the variables and parameters used to calculate climate change vulnerability do not take into consideration coastal aspects, such as coastal erosion, coastal flooding, etc.) and that the sensitivity calculation is focused on the agricultural sector.

The final derived CCV for each district, as well as the total population, is shown in Figure 7.

Figure 7 l Climate change vulnerability scores for Ghana's 216 districts



Source: (Pwamanng, Appah-Sampong, & Oppong-Boadi, 2020)

Based on the result for the 4NC, the Northern Region was the second most vulnerable region, and Tamale is ranked number **64** (out of 216 districts) in terms of climate change vulnerability.

3.4 Initial Assessment of Critical Climate Related Hazards

The preliminary critical climate-related risks can be assessed using a tool like the ***ThinkHazard! Tool***[3].

Table 1 I Summary of critical climate-related hazards for TaMA

Hazards											
District	River flood	Urban Flood	Coastal Flood	Earthquake	Landslide	Tsunami	Volcano	Cyclones	Water Scarcity	Extreme Heat	Wildfire
Tamale	Medium	Very Low	N/A	Very Low	Very low	N/A	N/A	N/A	Low	High	High

Source: ThinkHazard! (Global Facility for Disaster Reduction and Recovery (GFDRR) , 2022)

The results shown in Table 1 indicate that the critical climate-related hazards for TaMA are Extreme Heat (high), Wildfire (high) and River Flooding (medium). It is interesting to note that urban flooding was not considered as high risk, and yet there is increasing evidence that an increase in urban flooding is a major area of concern for Tamale, and for most cities in Ghana. This is likely because *ThinkHazard Tool* is based mainly on the result of the climate models, i.e., based on the relative change in critical climate variables and does not necessarily take into consideration the underlying vulnerability of each location. It is also likely based on the previous climate models, whereas the more recent models indicate increased flooding risk.

Similarly, the climate change related risks associated with water scarcity is considered to be low despite apparent challenges with regard to ensuring a reliable water supply for Tamale. The reason for why water scarcity is a low risk, is that that water demand consistently exceeds the available supply which is attributable more to factors such as technical-economic and financial aspects in expanding the systems' capacities, as well as the distribution network (the outreach) of the schemes, rather than to the scarcity of the water resource or a lack of water availability. Even the current low flow regime of the White Volta River, which provides the bulk of the water supply to Tamale, is not considered to be a limiting factor for a reliable water supply. Under climate change conditions with envisaged reduced flows in the basin, storage facilities through the construction of dams could provide enough surface water sources for urban water supply schemes (WRC, 2008). However, other factors such as catchment degradation that affect the physical infrastructure, such as flooding, do pose a risk to water security.

3.5 Stakeholder Engagement

Climate change risk assessment should be a participatory process, sensitive to issues of gender, youth, and the possible presence of vulnerable groups (indigenous peoples, for example). To this end, the involvement and commitment in the assessment process of all interested and affected parties (I&APs), including members of local communities, should be integrated throughout the risk assessment process and phases. The level of engagement varies, depending on the aims and objectives of the study, the relevant scope, the available time, and the process to be followed.

3 https://thinkhazard.org/en/

To inform the development of the **climate risk assessment for TaMA,** the project team undertook a site excursion from 28 November 2022 until 9 December 2022. The purpose of this visit was to engage with key stakeholders in Tamale, as well as at a national level, with the purpose of:

- introducing the NAP (National Adaptation Plan) project and process;
- providing stakeholders with an overview of climate change, the potential impacts and various aspects that will be evaluated in the climate change risk assessment;
- presenting the outcomes of the down-scaled temperature and precipitation scenarios;
- validating the findings of the climate change projections; and
- identifying critical climate-related risks and collect data and anecdotal evidence in order to better understand these risks, their impacts, and the adaptive capacity of local communities.

Figure 8 I Stakeholder engagement session in Tamale

Following the engagement with key stakeholders in Tamale, a second 2-day workshop was held in Accra with national-level stakeholders and government representatives, with the purpose of:

- presenting the outcomes of the down-scaled temperature and precipitation scenarios, including the evidence and data provided by the MMDAs on the priority risk domains;
- capturing additional information on the critical climate-related risks and adaptive capacity; and
- providing training on the approach to undertaking a local-level climate risk assessment.

The sessions in Tamale were co-ordinated through the local EPA offices. A joint stakeholder session was held on 29 November 2022, which included various departments of the Assembly, together with public and private sector stakeholders. In total, 51 participants (excluding the project team) attended the workshop and contributed to the bottom-up risk assessment (stakeholder list provided in **Appendix B**).

Using the climate projections and other studies relating to the potential impact of climate change on the critical risk domains in Tamale, together with the key findings from the interactive sessions and additional data collection, the project team was able to proceed with the local-level risk assessments.

3.6 Identification of Priority Risk Domains and Assets

To determine the specific priority risk domains considered for each of the MMDAs, it was necessary to consider the location and the specific economic activities in each area that would determine which would be the most appropriate risk domains to address as part of the CCRA.

The criteria used in selecting first- and second-order risk domains, is shown in Figure 9.

Figure 9 I Criteria in selecting first and second order risk domains

- For **first order risk domains:**
  - Magnitude/severity of projected change in risk
  - Vulnerability of second order (economic) categories to the first order (biophysical) risk category
- For **second order risk domains**:
  - Importance to local economy
  - Level of vulnerability/exposure
- For **both first and second order domains**:
  - A non-overlapping list of categories across the two case studies to be representative of approaches.

A preliminary list of first and second order risk domains considered relevant for TaMA was developed, based on a desktop study of available data (Table 2) and presented to the key stakeholders, to determine the relative importance to the MMDA. This list was then discussed with the key stakeholders, and the first and second order risk domains selection was finalised (Table 3).

Table 2 I Considerations for identifying critical first and second order risk domains for TaMA

Second order risk domains	First order risk domains
Tamale City, and the region surrounding it, are recognised as the "breadbasket" of Ghana. The potential climate change risks to agriculture and livestock farming will be a very important consideration, in particular changes in **crop and livestock productivity**.	Important first order risks that support agriculture, water security and human health, are **water resources** availability and quality, **flooding, droughts, fire risk** and **natural ecosystems**, particularly in terms of the potential for ecosystem-based adaptation. These are therefore proposed as the key first order risk domains for Tamale City. The impact of **flooding** is also a particular concern for TaMA for multiple sectors.
Water security, in terms of reliability of supply, is a significant challenge for all cities in Ghana and is particularly sensitive to the impacts of climate change. This is likely to be of much greater concern in the dry land ecosystem region and this is therefore an important second order risk.	
The potential impact of heat on **human health** is another important second order risk domain. ThinkHazard classifies the extreme heat hazard in TaMA as High.	

Table 3 l Identified critical first and second order risk domains selected for TaMA

First Order Risk Domain	Second Order Risk Domain
Water Resources (surface water) Fluvial Flooding Droughts Fire Risk	Water Security (water and sanitation) Agriculture – Crop Productivity Agriculture – Livestock Productivity Health (heat stress, diseases, etc.)

Through the engagement in the stakeholder workshop, the following critical systems and assets were identified and become the primary focus of the local-level climate change risk assessment for TaMA.

- Damage to water treatment plant
- Water supply systems and infrastructure
- Water resources
- Communities along riverbanks
- Urban flooding and storm water management
- Damage to road infrastructure
- Agriculture
- Health systems

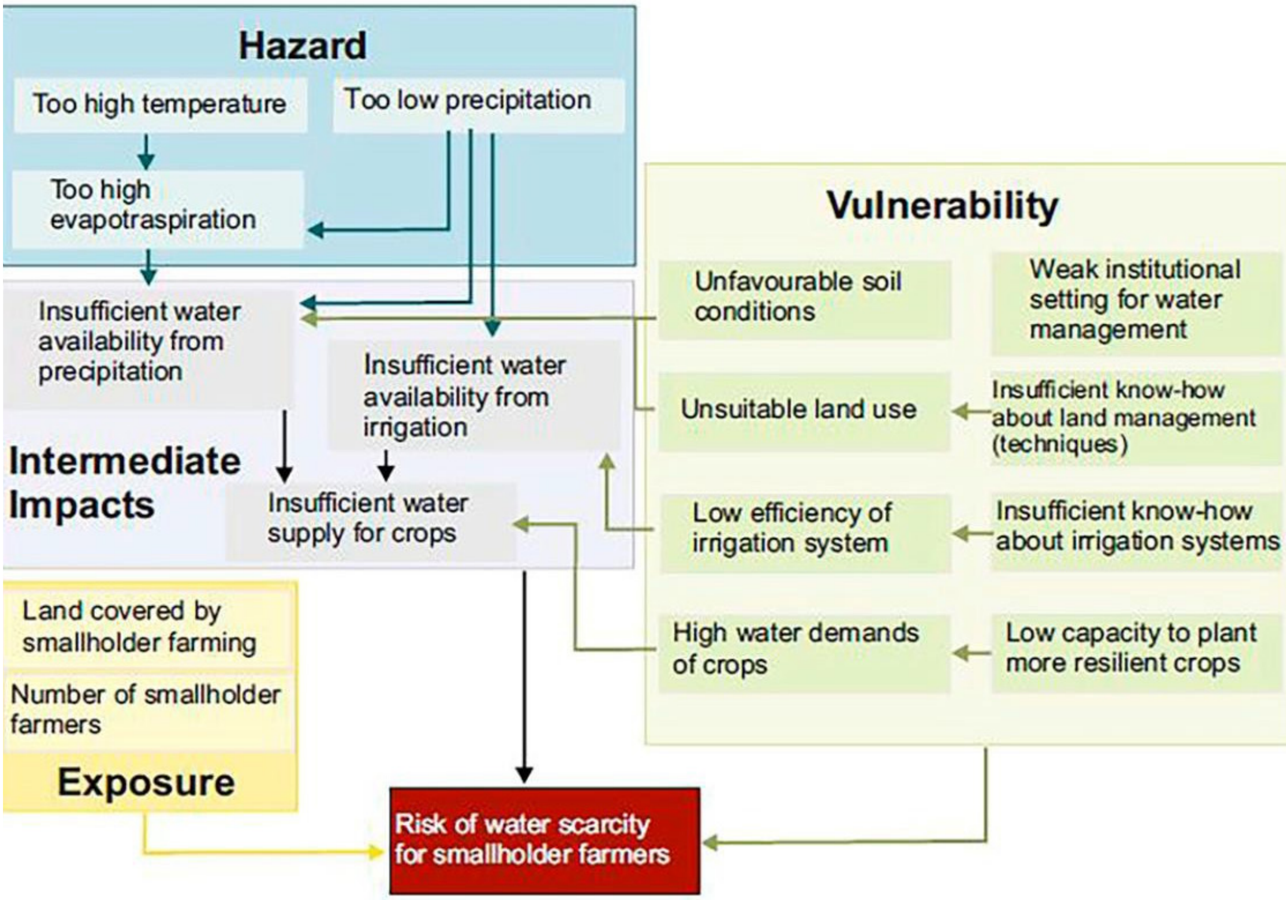
The related climate hazards and individual impact chains developed to inform the climate risk assessment for these priority systems and assets, are presented in Section 8.

3.7 Overview of Impact Chain Analysis

An impact chain diagram (or risk flow diagram) is an analytical tool that helps to better understand, systematize, and prioritize, the factors that drive risk in a system. They are generally represented as a schematic that allows the key components of the conceptual framework, presented in the previous section, to be identified. This means that, for each impact that causes a risk, the components of the dangers that cause it, the exposure that may be affected, and the vulnerability that relates the level of damage to the exposure to the magnitude of the risk, are identified and represented. impact.

The impact chain (IC) method is a conceptual framework used to capture the most relevant risk factors contributing to a specific risk (Menk, et al., 2022). It structures the risk factors based on the IPCC AR5 risk definition, defining risk into the hazard, exposure, and vulnerability factors (IPCC, 2014; Huq et al, 2014). An example for water scarcity risk for smallholder farmers, is shown in Figure 10 below.

Figure 10 I An example impact chain for water scarcity risk for smallholder farmers



Source: (Menk, et al., 2022)

An example of a generic climate hazard impact chain for key risks in Ghana, is shown in **Appendix A**.

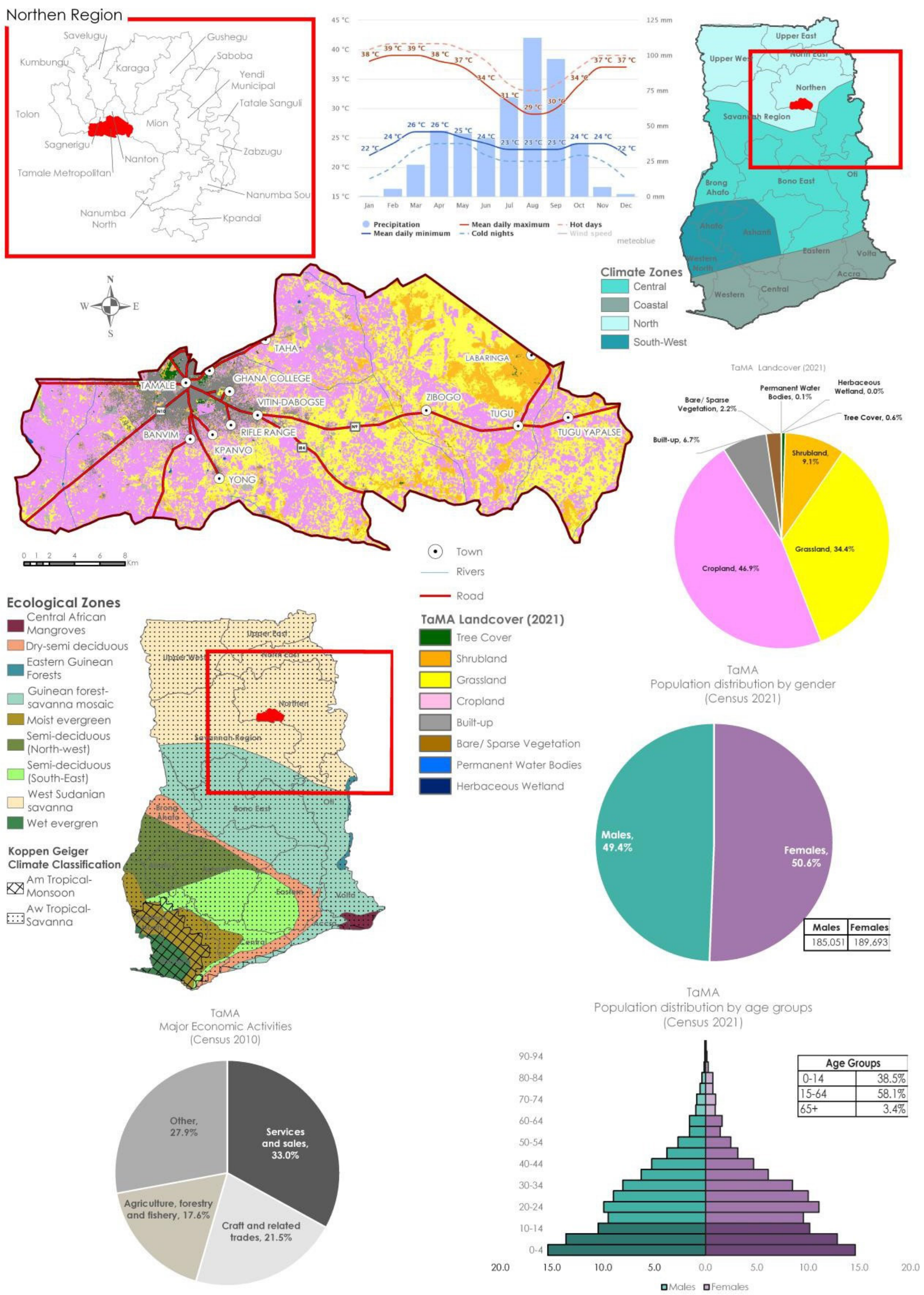
This includes a summary of all the relevant climate hazards and the likely first and second order risk domains. Some of the causal links are shown in the impact chain diagram. This, however, will need to be adapted for use in each specific MMDA, based on the identified priority hazards and risk domains.

4

Overview of Tamale Metropolitan Assembly

This section provides a high-level overview of Tamale Metropolitan Assembly (TaMA).

Figure 11 I Land use in TaMA, 2021



TaMA is located in the Northern Region of Ghana, at an elevation of approximately 180 m above sea-level, and has an area of approximately 650 km2 (PHC, 2010). TaMA shares boundaries with the Sagnarigu District to the northwest, Mion District to the east, East Gonja to the south and Central Gonja to the southwest.

TaMA is located in the Northern Climate Zone of Ghana. The four homogenous climate zones were identified through the analysis of trends in observed climate data, as well as in similarity to the expected changes due to climate change, during the analysis of downscaled temperature and precipitation scenarios for the periods 2030-2040, 2050-2060 and 2070-2080. As a result, they are expected to respond in a similar manner as to future climate change scenarios under the various global emission scenarios.

The average annual temperature in Tamale is around 28°C. The mean daytime temperatures range from 28°C (December and mid-April) to 43°C (March, early April) , and the mean night-time temperatures range from 18°C (December) to 25°C (February, March).

The mean annual rainfall is around 1100 mm within 95 days of rainfall, in the form of tropical showers (intense rainfall). The climate diagram for the average temperature and precipitation for Tamale shown in Figure 11, is based on 30 years of hourly weather model simulations (Source: Meteoblue.com).

According to the 2021 Ghana Population and Housing Census, TaMA has a total population of around 374 744, comprising 185 051 (49.4%) males and 189 693 (50.6%) females (Figure 11). This represents 16.2% and 1.2% of the regional and national population respectively. The population pyramid included in Figure 11, shows the distribution of ages across TaMA population, divided down the centre between male and female members of the population and clustered by age groups in the horizontal bars. The graphic starts from youngest at the bottom, to the oldest at the top.

In 2010, the total population of TaMA was 223 252, indicating that the population of TaMA has increased by 151 492 over the past 11 years. This increase represents an average growth rate of 3.68% per year. Table 4 provides an extract of the Ghana Population Estimates for the period 2015 to 2030, spaced in three-year intervals, and Figure 12 shows the projection of the annual population growth rate (%) for the period 2016 to 2030, based on the U.S. Census Bureau data.

Table 4 I Population projections, 2015-2030

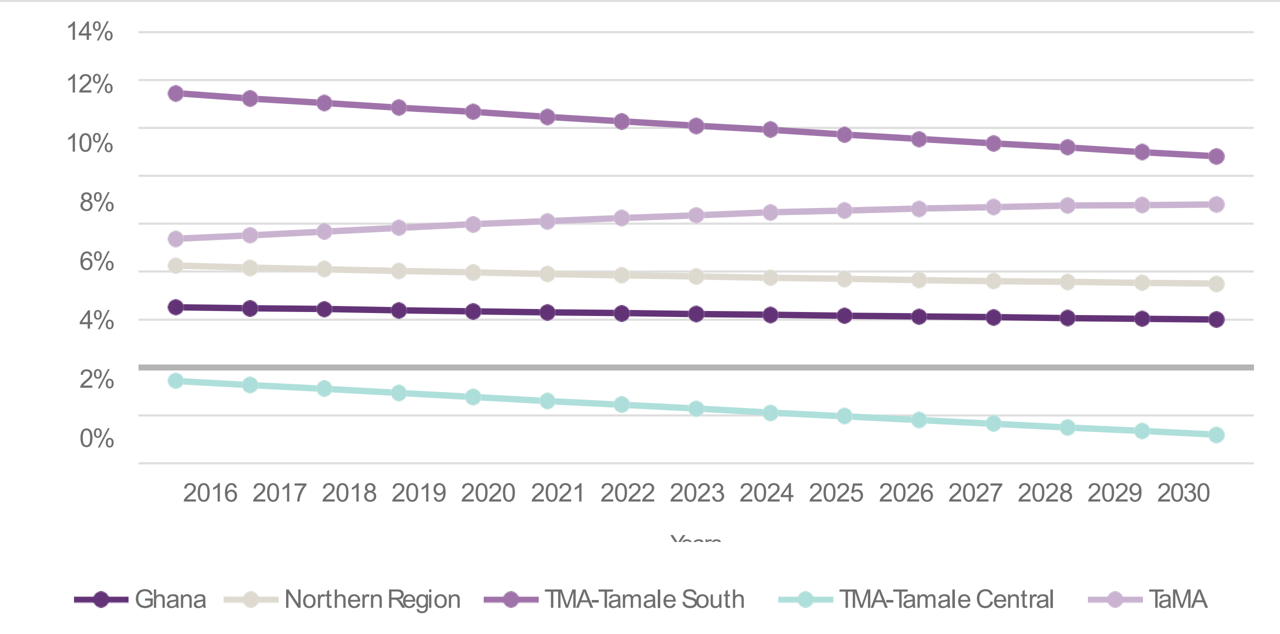
Area	2015	2018	2021	2024	2027	2030
Ghana	28 062 643	30 197 001	32 372 889	34 589 092	36 843 036	39 138 651
Northern Region	1 910 050	2 159 404	2 426 846	2 713 986	3 022 362	3 354 357
TMA-Tamale South	139 010	191,347	259 315	346 079	454 835	589 013
TMA-Tamale Central	142 487	139,403	134 318	127 514	119 316	110 063
TaMA (Total)	281 497	330 750	393 633	473 593	574 151	699 076

Source: data retrieved from the United States Census Bureau

The Northern Region of Ghana, where TaMA is located, is considered to the be the “breadbasket” of Ghana due to the high level of agricultural importance in the region. Within TaMA itself however, the economic sectors with the highest levels of employment, are the service and sales industries (33.0%), followed by the craft and related trades sector (21.5%).

The proportion of employed persons engaged in skilled agriculture, forestry and fishery, is 17.6%, followed by 12.5% for themanufacturing sector. Wholesale, agriculture, retail and manufacturing account for 64.1% of the industrial base. According to the 2010 Census data, the economically active population was 63.3%, of which 92.6% were employed, and 7.4% were unemployed. The proportion of economically active men was 65.5%, of which 92.8% were employed, and 7.2% unemployed. The proportion of economically active women was 61.1%, of which 92.3% were employed, and 7.7% unemployed (GSS, 2014).

Figure 12 I Projection of the annual growth rate between 2016 and 2030



Source: data retrieved from the United States Census Bureau

The main water source in TaMA is pipe-borne water, served by an aged reticulation network that does not reach all the urban communities in the MMDA, especially those located on elevated land areas. Other sources of water are municipal water systems, mechanized bore holes, wells, dams and dugouts (Tamale Metropolitan Assembly, 2020). Most households in TaMA depend on either pipe-borne water outside their dwelling, or pipe-borne water inside their dwelling (41.4% and 39.8% respectively). Rural communities, specifically the Dungu community, rely largely on small dams for drinking water (Alhassan & Kwakwa, 2014). Inadequate access to safe drinking water can force households to utilize water purifying methods such as cloth filtration and require that women and children devote their time to finding safe water sources (Alhassan & Kwakwa, 2014).

The Ghana Water Company Limited (GWCL) extracts raw water from the Nawuni abstraction point, at approximately 35 km north-west of the City, and treats it at the Dalun Water Treatment Plant (WTP) for reticulation to TaMA and surrounding communities, where approximately 65% of the population has access to the piped water supply network. However, water supply to the City of Tamale and surrounding areas is severely compromised by sand mining activities and land degradation in the catchment, which is causing sedimentation of the river and the intake works.

The "Composite Annual Action Plan 2022" document outlines the development goals and strategies of TaMA for the year 2022. The Metropole identifies inadequate infrastructure as a key development issue. To address this, the assembly plans to construct new roads and to rehabilitate existing ones, to construct drains and culverts and to install streetlights.

In terms of economic growth and development, TaMA seeks to support the growth of the agricultural sector, promote investment, and improve the business environment to facilitate trade and economic development. These include the establishment of an agro-processing centre, the development of a modern abattoir, and the creation of an investment promotion unit.

To promote trade and investment, TaMA plans to develop a new market complex and establish an investment promotion unit. To address the issue of low revenue generation, TaMA plans to improve property rates collection by intensifying property rates enforcement and by implementing an electronic property rates billing system. In terms of local governance and participation, TaMA aims at improving citizen participation and promoting transparency and accountability. These include the establishment of community information centres and the conduct of regular town hall meetings.

Appendix C provides more background information about TaMA.

5 Climate Change Vulnerability

The vulnerability to potential climate change impacts is determined based on sensitivity and adaptive capacity. The current vulnerability is characterised by both socioeconomic conditions, including the dependency on high-risk sectors such as agriculture, as well as on the institutional capacity to manage and mitigate the potential for increasing climate change related risks, that includes floods and droughts. The future level of climate change vulnerability will be determined based on the socioeconomic development pathway as described in the previous section and summaries below, in terms of future vulnerability.

5.1 Current Vulnerability - Sensitivity and Adaptive Capacity

Tamale is already experiencing significant challenges due to population growth, failing infrastructure and climate change. With a rapidly growing population, limited water resources, and a fragile economy largely dependent on farming and trading, the City's vulnerability, exposure, and adaptive capacity to climate change, are crucial factors to consider in building the resilience of the people of Tamale.

5.1.1 Economic Vulnerability

Tamale's vulnerability to climate change is primarily due to its geographic location and socioeconomic factors. The City is situated in the Northern Region of Ghana within the Guinea savannah belt, known for its semi-arid climate and seasonal rainfall patterns. The majority of the population depends on farming and trading for their livelihoods, rendering them particularly susceptible to the impacts of climate change on agriculture and food security. Furthermore, the Northern Region is one of Ghana's three poorest regions, exacerbating people's vulnerability to climate risks. The City's economy needs to be developed and diversified further to enable the necessary investments in climate adaptation measures.

5.1.2 Physical/Environmental Vulnerability

Tamale is exposed to multiple climate change-related hazards, including the Harmattan wind during the dry season from November to January (UN Habitat, 2009). This wind contributes to soil erosion and decreased fertility, negatively affecting agriculture. Limited water resources, with few seasonal rivers, exacerbate the local water supply challenges, threatening farmers' and traders' livelihoods, as well as water security for households. The main water supply for Tamale is from the White Volta River which is impacted by the activity of upstream users, poor catchment management and sand mining. These combine to increase the vulnerability of Tamale to the potential impacts of climate change on water security. Current initiatives such as improvements to the water abstraction point and water treatment plant, as well as the potential for establishing a Tamale Water Fund, will help in reducing this vulnerability.

During the rainy season, flooding caused by heavy precipitation and water releases from the upstream Bagre Dam, poses a problem. This flooding damages infrastructure and degrades water quality due to sediment. Catchment degradation and sand mining in the region further heighten the vulnerability of Tamale communities. Climate change is anticipated to worsen these issues, with predictions of rising temperatures, unpredictable rainfall and extended dry seasons. Flooding risk is increased in Tamale due to a lack of maintenance of the stormwater system, unplanned development and deforestation.

5.1.3 Social Vulnerability and Adaptive Capacity

The City's rapid population growth, at a rate of 3.5% per annum (UN Habitat, 2009) , places significant pressure on the limited natural resources, such as water and arable land. As the population increases, farmers are being pushed into less favourable locations to continue production, including flood plains and along public drains where wastewater is used for irrigation. To prevent food security from deteriorating, there is a need to protect urban and peri-urban agricultural lands by mapping and preserving the high-potential production areas (Kuusaana & Eledi, 2015). Furthermore, the region's relative poverty and limited infrastructure hinder the development and implementation of effective adaptation strategies. Nevertheless, Tamale has a strong sense of community, and people tend to rely on traditional social support systems. However, the City needs to strengthen the capacity of the existing social systems and institutions, both governmental and NGOs, to facilitate collective action to address climate change.

The level of awareness of climate change risks and adaptation options also needs to be improved to enhance the adaptive capacity and to enable traditional systems to support the communities. As noted previously, TaMA has a reasonably high level of adaptive capacity as defined by the District League Table used to assess adaptive capacity as part of the Fourth National Communication. According to this indicator, Tamale is ranked at 64 out of 216 districts in Ghana.

5.2 National and Sub-National SSPs

A parallel study has considered the development of local-level socioeconomic development scenarios that can assist with evaluating the potential for future climate change risk and vulnerability under different future scenarios. These national and local-level socioeconomic development scenarios were developed from four of the global Shared Socioeconomic Pathways (SSPs), as developed by O'Neill et al. (2015).

These four selected SSPs are summarized below:

1. **Sustainability – Taking the Green Road:** This pathway is characterized by more inclusive global development and improved management of global commons (the earth's shared natural resources), low global population growth and slower economic development, leading to a relatively low resource and energy demand. Environmental technologies are favoured. Global, national and regional institutions are strong and flexible, and human well-being has improved.

2. **Fossil-fuel Development – Taking the Highway:** This SSP is characterized by competitive markets, innovation and participatory societies that produce rapid technological progress and development of human capital as a means to achieve sustainable development. It is a world of intensive fossil fuel development, high energy demand and rapid technological progress, but is also characterized by a focus on health, education and institutions to enhance human and social capital.

3. **Inequality – A Road Divided:** This SSP is characterized by increasing inequalities, both between and within countries, the concentration of power within a small elite, and moderate economic growth in the industrialized world, with a large, vulnerable population on the rest of the planet. Technological development is uneven and global markets are volatile due to prevailing political uncertainties.

4. **Regional Rivalry – A Rocky Road:** This SSP is characterized by resurgent nationalism, competitiveness and security, along with weak global institutions. Other features are trade barriers,

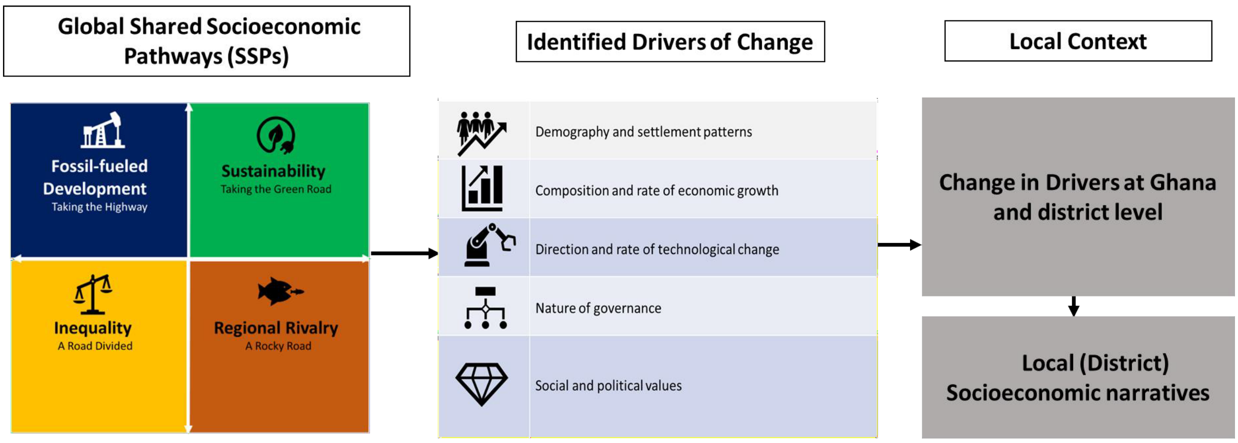
authoritarian governments and highly regulated economies. Economic development is slow but material consumption intensive.

The four selected SSPs have been applied in terms of identified key drivers of change at the national level, for three key sectors (agriculture, energy, and health), and at the local level for Tamale and Sekondi-Takoradi Metropolitan Assemblies. The specific details of these local-level socioeconomic development scenarios are still being finalised but have been assessed in the following section in terms of the potential impact that these alternative development scenarios will have on climate change vulnerability.

The key drivers of change, used to define the SSPs, are shown in Figure 13 and consist of the following:

(1) demography and settlement patterns, (2) consumption and rate of economic growth, (3) direction and rate of technology change, (4) nature of governance, and (5) social and political values.

Figure 13 I Adapted approach to develop local socioeconomic narratives



5.3 Future Climate Change Vulnerability

Under the **Sustainability future scenario**, overall climate change vulnerability is reduced by means of investments in ecological infrastructure and pro-active urban planning. Improvements in agricultural practices and successful water resources development through the One Village One Dam project have also reduced sensitivity to drought and any potential impact of climate change on rainfall availability. In addition, the efforts made to reduce deforestation and to reduce plastic pollution have also reduced the potential risks associated with any possible increase in flooding risk. This is also as a result of improved collaboration between local government and national government around protecting critical infrastructure, and the increased provision of basic services and improved health care facilities.

Under the **Fossil-fuel development scenario**, the potential impacts of climate change will be greater, but the sensitivity and adaptive capacity could potentially be strengthened if these developments result in a stronger local economy, and if these benefits are used to reduce the vulnerability to climate change. This could include for example investing in improved water supply infrastructure and improved stormwater management systems, and providing social safety nets for the most vulnerable. If these pro-active investments are not made, then there is likely to be an increase in inequality, which will result in an overall increase in the vulnerability to climate change, as well as other risk factors.

Under the **Inequality – Road Divided** scenario, the local government of Tamale receives limited support from the central government, and therefore have to solve most of their problems on their own and with limited resources. This could lead to innovative solutions and reduced climate change vulnerability, but it is more likely to drive inequality, with those who have the means being able to adapt to increase climate-related risks by installing their own water supply systems or flood protection, and with the vast majority of the population without the means to do so, becoming even more sensitive and vulnerable to climate impacts.

Under the **Regional Rivalry – Rocky Road** scenario the world is characterized by competition, and a weakening of the structures for international co-operation. There is limited inflow of aid in all forms, and this reduces the availability of funds to undertake relevant projects. As a result, the vegetation of Tamale and its environs will come under threat due to the lack of commitment to maintain such reserves. This increased regional competition will increase the pressure on natural resources, resulting in further deforestation and catchment degradation, and increase impacts due to sand mining. These will result in a significant increase in the sensitivity and potential impact of any increases in climate-related risks. At the regional level, a lack of collaboration with upstream countries will make Ghana far more vulnerable to the impacts of upstream developments on water supply, and could also result in increased migration.

6

Observed Climate and Trends

6.1 National Summary of Climate and Trends

Ghana's generally tropical climate is strongly influenced by the West African monsoon winds, which vary slightly along with the country's varied topography. With most of the rain falling in intense storms of short duration, the country is vulnerable to extreme events such as heavy rainfall (on average 44 mm per day) resulting in heavy runoff and erosion, especially at the beginning of the rainy season. At the same time, the long dry season in the north has led to serious droughts in the region (Ministry of Foreign Affairs of the Netherlands, 2019).

Ghana's high degree of vulnerability to climate change poses a threat to growth and development.

There is evidence of a temperature increase over the past decades. Mean annual temperature has increased by 1.0˚C since 1960, an average rate of 0.21˚C per decade, with the strongest increase between April and July (+0.27°C per decade). The rate of increase has been more rapid in the north of the country than in the south. Moreover, the number of 'hot'[4] days has increased significantly in all seasons except between December and February, and 'hot nights' has increased significantly in all seasons (by 13.2% and 20% respectively between 1960 and 2003), while the number of 'cold' days and 'cold' nights[5] has decreased (by 3.3% and 5.1% respectively over the same period).

Annual rainfall in Ghana is highly variable on interannual and decadal timescales. This means that long-term trends are difficult to identify. There is no evidence of a trend in the proportion of rainfall that falls in 'heavy'[6] events between 1960 and 2006. (McSweeney, New, & Lizcano, 2012). Although interannual and decadal rainfall were highly variable, overall rainfall saw a well-defined cumulative reduction of 2.4% per decade (USAID, 2017). No clear trend has been observed in the intensity or frequency of extreme rainfall events. (Ministry of Foreign Affairs of the Netherlands, 2019).

6.2 Local-Level Climate and Trends

The mean annual temperature in Tamale is currently just below 29°C but has risen by approximately 1°C since the late 1970s. Since 2000, the mean annual and decadal temperatures have consistently been more than 28.4°C. Figure 14 shows the mean annual temperature changes, including its trend (dashed blue line) and the annual temperature anomalies, for the past 40 years in Tamale. In the lower part of the graph, blue indicates years colder than the average, and red indicates warmer years.

Precipitation in Tamale, and the Northern Region, experienced a high degree of interannual and interdecadal variability. However, since the 1960s, an overall reduction in cumulative rainfall per decade was observed. Changes in decadal rainfall declined in the middle of the country, with more intense rainfall events occurring in

4 'Hot' day or 'hot' night is defined as the average temperature being exceeded on 10% of days or nights in current climate of that region and season.

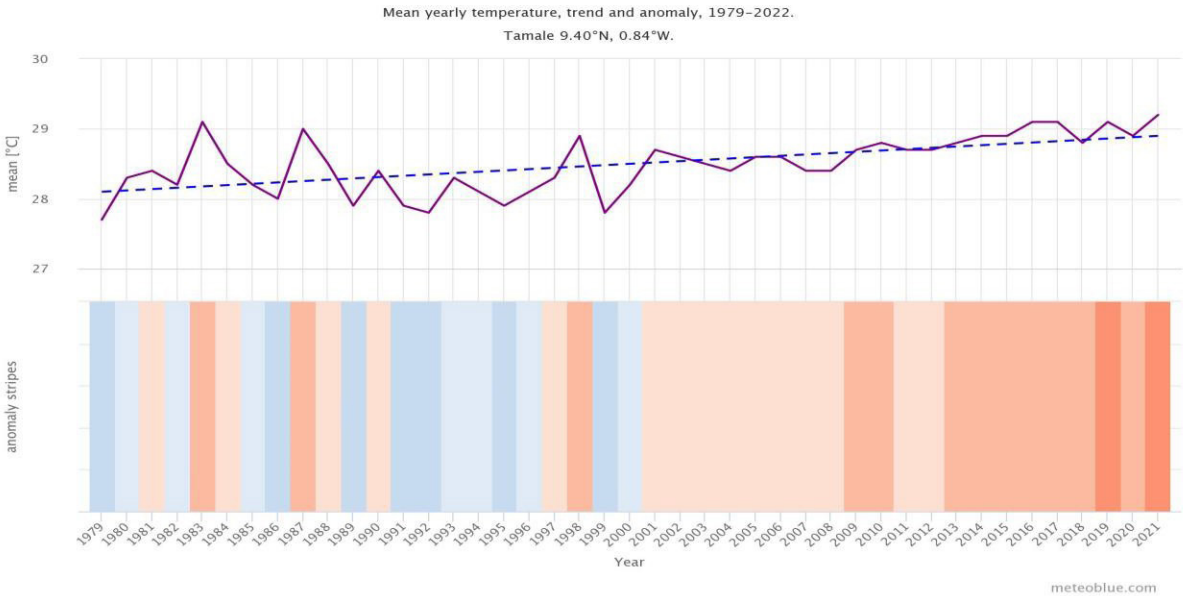
5 'Cold' days or 'cold' nights are defined as the average temperature below not being reached on 10% of days or nights in cur rent climate of that region or season.

6 A 'Heavy' event is defined as a daily rainfall total that exceeds the threshold on 5% of rainy days in current the climate of that region and season.

both the north and south of the country, indicating an increase in the intensity of rainfall events and a possibility of increased dry spell durations (The World Bank Group, 2021).

Figure 15 shows annual precipitation and trend (dashed blue line) for the past 40 years for Tamale. In the lower part, the graph shows the annual precipitation anomalies, where each coloured stripe represents the total precipitation of a year – green for wetter years, and brown for drier years. This figure confirms the general long-term trend of decreasing rainfall for Tamale since the 1980s. However, it is also possible to see that since the mid-1990s, this trend has tended to flatten, and there is even a suggestion of an increasing rainfall trend for Tamale since early 2000. Rainfall continues to be highly variable for Tamale, but there does not appear to be a continuation of the downward trend in mean annual precipitation (MAP) that was experienced during the 1980s and 1990s, suggesting that climate change may in fact be contributing to a general increase in MAP, rather than a further reduction in MAP.

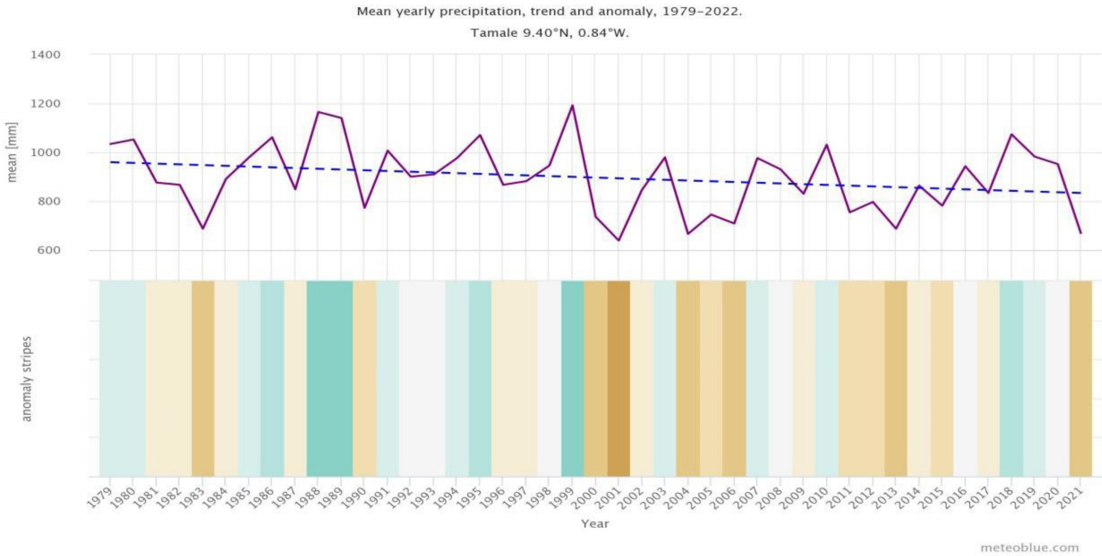
Figure 14 I Mean annual temperature, trend and anomaly in TaMA, 1979-2022



Source: (www.meteoblue.com, 2022)[7]

7 The data source used is ERA5, the fifth generation ECMWF atmospheric reanalysis of the global climate, covering the time range from 1979 to 2021, with a spatial resolution of 30 km.

Figure 15 l Mean annual precipitation, trend and anomaly in TaMA, 1979-2022

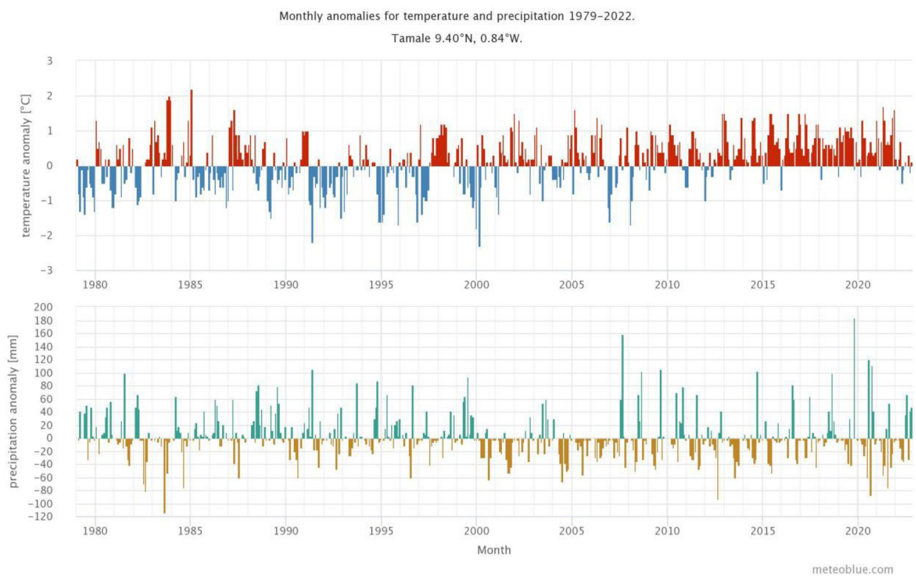


Source: (www.meteoblue.com, 2022)

Figure 16 shows the temperature and precipitation anomalies for every month between 1979 and 2022, comparing the mean monthly values with the 30-year climate mean of 1980-2010. The top graph shows the temperature anomaly, and by how much each month was warmer or colder than the average – red months were warmer and blue months were colder. It is possible to observe an increase of warmer months over the years, which reflects the global warming associated with climate change.

The lower graph shows the precipitation anomaly, and if there was less or more precipitation than the long-term monthly average – green months were wetter and brown months were drier. It is possible to observe that since 2000, the number of drier months has been increasing, and that the anomaly values of both wetter and drier months have been greater, especially for the wetter months. This indicates that, while there might be a potential overall drying trend, this is interspersed with very wet months.

Figure 16 l Monthly anomalies for temperature and precipitation in TaMA, 1979-2022



Source: (www.meteoblue.com, 2022)[8]

8 The data source used is ERA5, the fifth generation ECMWF atmospheric reanalysis of the global climate, covering the time range from 1979 to 2021, with a spatial resolution of 30 km

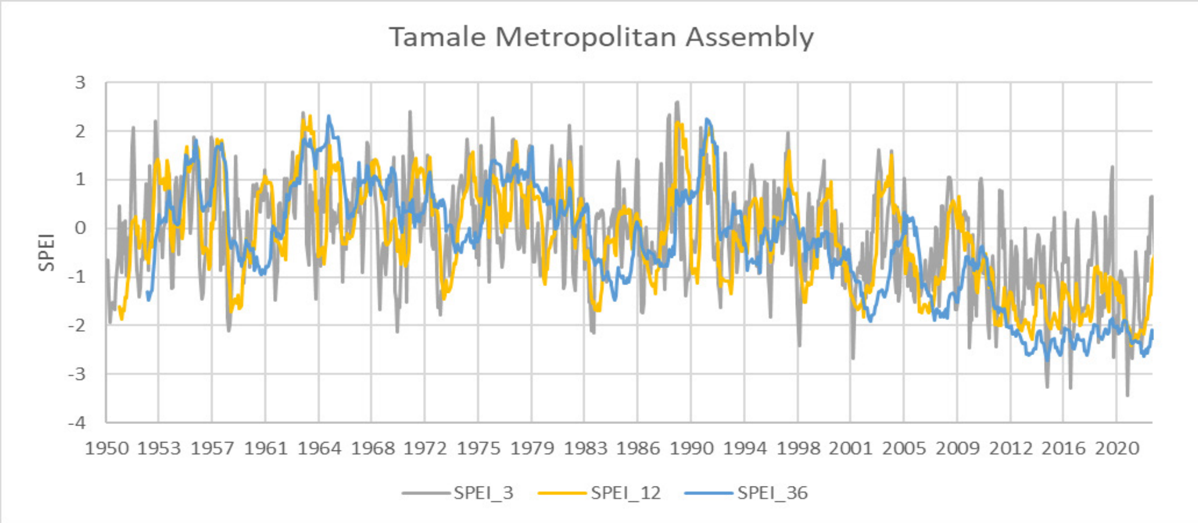
A preferable method to use for the identification and analysis of drought conditions, is the Standardized Precipitation Evapotranspiration Index (SPEI), as it can account for the possible effects of temperature variability and temperature extremes beyond the context of global warming. The SPEI represents the measure of the given water deficit in a specific location, accounting for contributions of temperature-dependent evapotranspiration, and providing insight into increasing or decreasing pressure on water resources. The SPEI can measure drought severity according to its intensity and duration, and can identify the onset and end of drought episodes (Beguería, Latorre, Reig, & Vicente-Serrano, 2022).

Negative values for SPEI represent dry conditions, indicating an increased likelihood of aridity and drought. Likewise, positive values indicate increased wet conditions and reduced likelihood of drought. This is an important indicator for the water sector regarding water quantity and quality of supply for human consumption, as well as for agriculture use and for the energy sector, as reductions in water availability impacts river flow and hydropower generating capabilities (The World Bank Group, 2021).

Figure 17 shows the observed trends in overall drying (negative SPEI) and wetting (positive SPEI) for Tamale, for three different timescales: 3, 12 and 36 months. This serves as an indicator of current trends for increasing risk of floods and droughts. From the figure it is possible to confirm that the conditions are becoming drier in Tamale over time, in particular over the past decade, but with increasing variability. It is clear from this figure that the past decade has seen the lowest overall drought indicator values (i.e., SPEI).

However, it is also interesting to note that the last major drought event was recorded as far back as 1983, both at a national and a local level. This implies that despite the overall drying trend, the communities within Ghana, and Tamale in particular, seem to be adapting well to this increasing drying trend. Seasonal drought and uncertainty regarding when the rains come, is still a challenge, and could be addressed through increased access to irrigation water for example, or seasonal forecasting and early warning systems. What is also clear is the variability of SPEI is increasing, and this is likely to continue even if the future climate scenarios suggest an overall increase in precipitation for Tamale and northern Ghana.

Figure 17 l Observed trends in the SPEI in TaMA, 1950-2010



Source: Data retrieved from https://spei.csic.es/database.html#p5

6.3 Observed Natural Hazards and Extreme Events

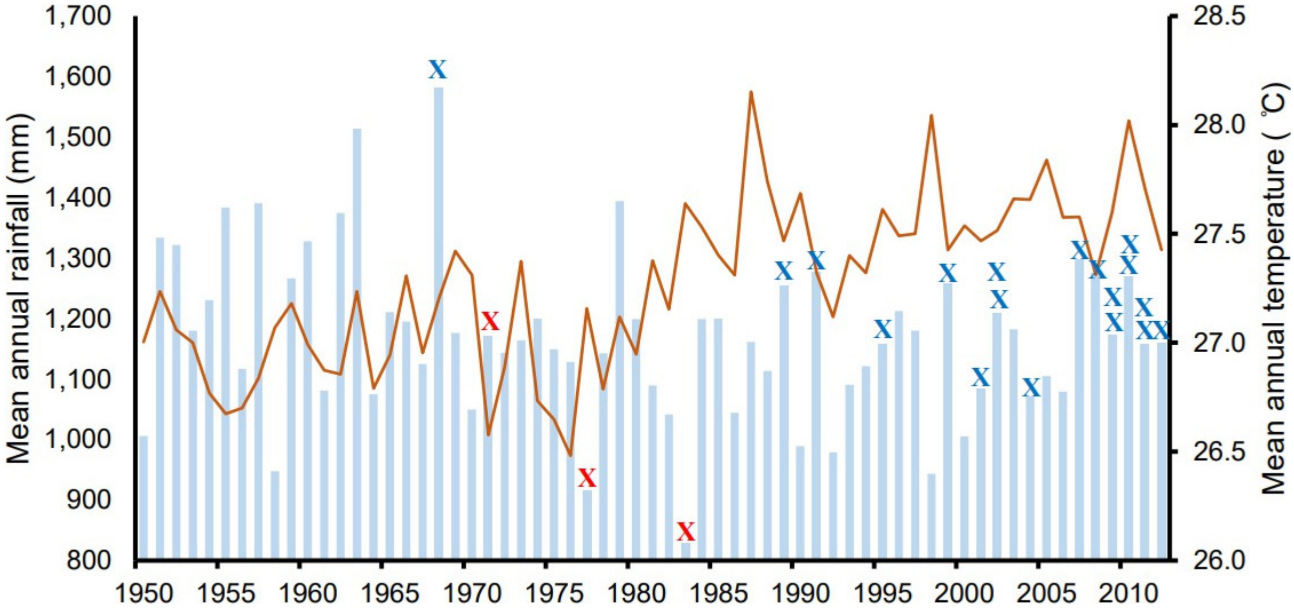
Ghana is highly exposed to extreme hydrometeorological conditions, such as floods, droughts and bush fires, which are linked to climate change. In the past 50 years, 22 major hydrometeorological events (19 flood events and three drought events) in Ghana have affected 16 million people, resulting in more than

400 deaths (Pwamanng, Appah-Sampong, & Oppong-Boadi, 2020). Extreme rainfall events have increased over the 1986-1995 period, including a high number of 24-hour maximum rainfall events, a trend that has continued in the last decade. Rising sea levels, drought, higher temperatures, and erratic rainfall, negatively impact infrastructure, hydropower production, food security, and coastal and agricultural livelihoods. Approximately a quarter of the population live along the coast in rapidly expanding urban areas, and are especially vulnerable to flooding and waterborne diseases. Drought and reduced rainfall also threaten access to reliable power sources, already erratic and insufficient.

The occurrence of both floods and droughts in the northern savannah region of Ghana is becoming a common phenomenon, associated with higher temperatures, more intense rainfall events, and more intense heat, facing associated risks of landslides. Insufficient rainfall during the major cropping season during the last major severe drought in 1982-1983, affected more than 12 million people.

Observed historical significant events recorded in Ghana since the 1950s are shown in Figure 18.

Figure 18 I Extreme climate events (droughts and floods) relative to mean annual rainfall (left-hand y-axis; bars) and mean annual temperature (right-hand y-axis; line) in Ghana from 1950 to 2012



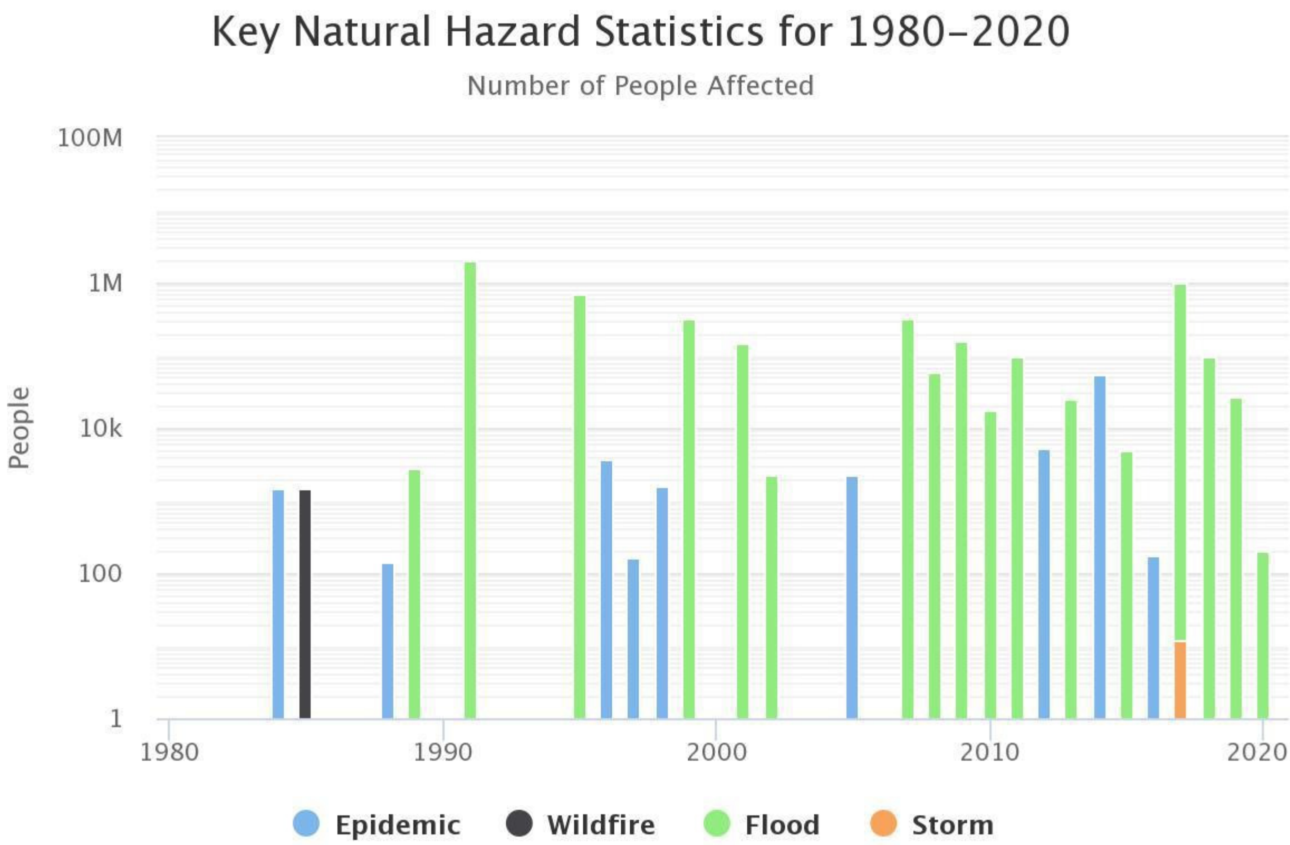
(Pwamanng, Appah-Sampong, & Oppong-Boadi, 2020)

Ghana suffered droughts during the following historical periods: 1968–73, 1982–84 and 1990–1992. However, the drought of 1983/84 is one of the most severe droughts in the country's history, as it triggered major hydrological imbalances that affected crop production throughout the country (Yaro, 2010).

More recently, flooding has become a frequent event and is of much greater concern, particularly when floods follow extended periods of drought. For example, the 2007 catastrophic floods in northern Ghana occurred immediately after a period of drought and affected more than 325,000 people, damaging the initial maize harvest (Ministry of Foreign Affairs of the Netherlands, 2019). With increasing variability in extreme events expected due to climate change, the likelihood of similar disasters in Tamale will increase.

A summary of natural hazard events that have occurred in Ghana since 1980, and the number of people affected, is shown in Figure 19, sourced from the Climate Change Knowledge Portal (CCKP). Figure 18 illustrates the extreme climate events (droughts and floods) relative to mean annual rainfall and mean annual temperature observed in Ghana from 1950 to 2012. These two figures indicate an increasing occurrence of flood-related disasters in particular, almost on a yearly basis since the late1990s, while there have been almost no severe droughts recorded since before about 1970.

Figure 19 I Summary of Key Natural Hazard Events for Ghana from 1980 to 2020



Source: WB Climate Change Knowledge Portal

The availability of historical information on catastrophic natural hazard events in Tamale is limited, but there is much anecdotal evidence suggesting that natural hazard events are becoming more regular.

Table 5 contains a list of climate-related hazard events that have been identified that occurred in Tamale and surrounding areas since 2007, particularly floods. This information was compiled based on information collected from newspapers and press releases publicly available on the internet.

Table 5 I Recent climate related hazard events identified in TaMA and surrounding areas

Date	Hazardous Event	Location	Impact	Reference
Jan – Dec 2022	391 Fires domestic fires – 203, commercial – 53, electrical – 42 and bushfires – 41. The rest are vehicular -19, institutional 12 and other fires – 21	Northern Region – (94 fires in Tamale Metropolis)	87 injuries recorded January and December recorded the highest number of fires (81), representing 20.72%	https://www.myjoyonl ine.com/northern-region-recorded-391-fires-in-2022/

Date	Hazardous Event	Location	Impact	Reference
November 2022	Water shortages	Zujung and Dundu communities	Residents (women and girls) were forced to travel several kilometres in search of water. Girls arrived late to school, even waking up earlier to search for water, because they had to battle with older women for water. Communities had to rely on murky water from hand-dug small pits behind the Zoomlion Company Limited offices on the Zujung cemetery road.	https://myjoyonline.c om/ water-crisis-hits-some-communities-in-tamale-metropolis/
August 2022	Flood (torrential rainfall)	Some parts of Tamale Metropolis. Areas including Gummani, Shishegu, Tunaayili, Jisonaayili, Kanvili, Kunyevela, Nyohini and Kanvili Tunaayili were most hard-hit by the flood.	More than 100 homes, motorbikes, cars and tricycles were submerged; roads submerged; bridge linking Gummani and Kanvili Tunaayili was washed away; footbridges were washed away; hundreds of residents were displaced	https://allafrica.com/s tories/202208150240 .html
Jan – Dec 2021	367 Fires	Northern Region		https://www.myjoyonl ine. com/northern-region-recorded-391-fires-in-2022/
August 2021	Flood (torrential rainfall)	Parts of Tamale Metropolis and the Sagnerigu Municipality, including Fou, Taha, Vettin, Gumani and Kalariga, among others in the Northern Regional capital	Several buildings wereinundated; several residents were displaced	https://www.myjoyonl ine.com/tamale-records-second-flood-in-3-days-more-residents-displaced/
October 2020	Flood (torrential rainfall)	Several communities (Sawaba, Taha, Gumani, Waterworks, Nyohini, Sagnarigu-Kukuo) in Tamale Metropolis and Sagnarigu Municipality of the Northern Region were flooded following heavy rainfall in the capital of Tamale	This flooding affected the transportation of persons, goods and commodities within parts of the metropole and several homes and properties were destroyed.	https://www.myjoyonl ine. com/communities -in-tamale-flood-after-heavy-downpour/
July 2017	Flood (torrential rainfall)	Most areas of Tamale were flooded	Loss of properties, several buildings were inundated, including the Tamale Teaching Hospital. Two people died and several residents were displaced.	https://www.africane ws.com/2017/07/27/g hana-hit-by-deadly-floods-in-the-northern-region-vp-visits-victims/

Date	Hazardous Event	Location	Impact	Reference
July 2016	Flood (torrential rainfall)	Northern Ghana – Communities affected include Sawaba, Belpela, Gumani, Datoyili, Kalariga, Sagnarigu, and Kulnyevila	Several houses, farms and livestock were gravely affected by the floods. One person died and several residents were displaced.	https://www.pulse.co m.gh/ece-frontpage/flood-tamale-floods-one-dead-tens-displaced/h6zklcm
September 2015	Flood (torrential rainfall)	Residents in Bilpela, Kalaraga and Darrigohi-Fong, suburbs of Tamale, were worst hit.	The heavy rains lasted for about an hour and a half, flooding homes of residents and destroyed many properties.	https://www.peacefm online.com/pages/loc al/ social/201509/2559 16.php
April 2014	Flood	The rainstorms destroyed houses in areas such as Gumbihini, Kukuo, Nyohini, Jakarayili, Kpanbegu and Sagnarigu, all within Tamale Metropolis.	Hundreds of Northern Ghana residents were displaced by severed rainstorms that battered towns and villages in parts of the Northern Region.	https://www.peacefm online.com/pages/loc al/ social/201404/1978 99.php
September 2007	Floods in the northern part of the country, immediately following a period of drought (overspill of the Bagre Dam in neighbouring Burkina Faso)	Upper East Region, Upper West Region, Northern Region and parts of the Western Region	The floods affected 332,600 people and caused the death of 56 according to the Government. Some 35,000 houses, 1,500 kilometres of road and thousands of hectares of crops were destroyed	https://news.un.org/e n/ story/2007/09/2316 22 https://reliefweb.int/re port/ ghana/ghana-situation-report-floods-nov-2007

Figure 20 I Aerial view of the affected houses in Tamale, August 2021 (Photo: Geoffrey-Buta)

FLOOD RISK NARRATIVE

In August 2021, five hours of heavy rainfall resulted in flooding of the low-lying areas of Taha, a community in TaMA, in the Northern Region of Ghana. Several houses and roads have been severely damaged.

Besides the substantial property and infrastructure damage, flooding can also lead to economic loss, disrupt access to basic services, displace whole communities, degrade the environment, and cause harm to human health, including mental health issues.

Floodwaters may carry untreated wastewater and runoff from contaminated/polluted sites, which could contaminate the land and water supply, causing several infections (eye, ear, skin and gastrointestinal) and diseases, even when floodwaters retreat, since bacteria and other pathogens may remain.

Flooding has a greater impact on poor and more vulnerable communities. Low-income households, people with disabilities, children, the elderly, and minority communities, are more vulnerable to the impacts of the floods, particularly if living in informal areas.

Flooding events such as these seem to be increasing in occurrence in Tamale, and across most of Ghana, and this is linked to climate change. However, their impact is also increased due to human activities, such as deforestation and illegal sand mining activities, as well as to poorly-designed drainage systems, uncontrolled development and a lack of maintenance of infrastructure.

As these events become more frequent and intense, the need for implementing early warning systems (EWS) is becoming more evident, together with more detailed flood modelling, more adequate stormwater design, cleaning of existing drains, and awareness campaigns, as well as improved catchment management and prevention of illegal mining and development.

Source: https://www.ghanaiantimes.com.gh/5-hr-downpour-renders-tamale-sagnerigu-residents-homeless/

Figure 21 I Residents of Tamale Metropolis queuing for water

WATER SECURITY RISK NARRATIVE

Water crisis hits vulnerable communities in Tamale Metropolis

In November 2022, the Joy Online reported on some parts of Tamale Metropolis experiencing severe water shortages as a result of their taps running dry, with the result that several communities were forced to rely on unclean water from small hand-dug "mupuka" pits. The water security crisis is being worsened by the onset of the harmattan winds, which is drying up most of the accessible water bodies.

Increasing temperatures and increased variability in rainfall is likely to increase the risk of similar water security risks, particularly for communities dependent on local sources and without access to a reliable water supply source such as from the much larger Volta River.

Providing access to a reliable water source, such as the Volta River, and increasing the storage capacity and improved catchment management of these sources, is critical in addressing the increasing water security risks due to population growth and climate change.

One of the activities that has been identified as adding to water security risks for Tamale, is poor catchment management and illegal sand mining. This not only impacts on water quality, but it also damages the treatment works and increases the risk of flooding.

A possible solution to this is the establishment of the Tamale Water Fund, which would see international donors and water users contributing to improved catchment management.

Other factors affecting the reliability of supply to Tamale are a lack of power for the water treatment works to enable transfer of water to Tamale, as well as ongoing challenges around the potential for developments in upstream countries, and increasing demands, which requires pro-active engagement at the national and regional level across the Volta River Basin.

Source: https://savannahnewsblogspotcom.blogspot.com/2012/02/tamale-water-crisis.html

Although no newspaper articles were found about recent droughts or dry spells in the region, there are a few journal papers available online about these events and their increase over the past 50 years in the region. Table 6 contains a list of some of those articles about rainfall variability and drought frequency in the Volta Basin, as well as in the savannah zone of Ghana, and particularly in Tamale.

Table 6 I Research papers on extreme weather events in TaMA and surrounding areas

Journal	Title & Author(s)	Abstract
Journal of Hydrology Regional Studies, 2022 **Aug 42:101143**	*Variability and changes in hydrological drought in the Volta Basin, West Africa* Solomon Gebrechorkos, Ming Pan, Peirong Lin, Daniela Anghileri, Nathan Forsythe, David Pritchard, Hayley Fowler, Emmanuel Obuobie, Deborah Darko, Justin Sheffield	Study region: Volta River Basin, West Africa. Study focus: Hydrological droughts have a wide range of impacts on societies and economic sectors such as agriculture and energy production. Analysis of hydrological droughts helps better plan and manage water resources under global change. This study analyses the spatial and temporal variability of hydrological drought occurrence (duration and severity) in the Volta River Basin during 1979–2013. We used the Variable Infiltration Capacity and vector-based routing (RAPID) models and high-resolution forcing data to simulate streamflow for 10300 river reaches. New hydrological insights for the region: Drought duration and severity show high spatial variability and large differences between the three decades (1980 s, 1990 s and 2000 s). Droughts are more severe in larger catchments as the flows are generally higher. The trend analysis shows a general decreasing trend (up to 5% per event) in drought duration in the north-eastern parts, and an increasing trend in the southern parts, of the basin. Drought severity shows an increasing and decreasing trend (up to ± 20%) in the south and north parts of the basin, respectively. Daily streamflow has a maximum correlation (up to 0.78) with upstream precipitation for the previous 30-days, with a clear signal of propagation from meteorological to hydrological drought, with an average lag-time of two weeks. The results indicate the need to consider site-specific and adaptive drought management measures to minimize the impacts.
Scientific African, 2020 **Nov, 10, e00571**	*Rainfall variabilities and droughts in the Savannah zone of Ghana from 1960-* *2015* Awo Boatemaa Manson Incoom, Kwaku Amaning Adjei, Samuel Nii Odai	In the savannah region of Ghana, water scarcity appears to be a frequent occurrence, which is expected to worsen with the anticipated reductions in the quantity of rainfall received. A better estimation of future occurrences, and the subsequent preparations, are hinged on a solid understanding of past climatic patterns. Given that, trends in rainfall were analysed using the non-parametric Mann-Kendal test for nine climate stations in the entire savannah zone of Ghana from 1960 to 2015. No significant trends were observed in annual rainfall for the entire study area as well as individual climate stations, except Wenchi, where a negative trend (Sen's slope = -3.30, p-value = 0.01) was recorded at a 0.05 level of significance The Standardised Precipitation Index (SPI) was used to study rainfall anomalies. Droughts were observed to be a regular feature of the climate, occurring at alternating intervals with wet periods. Recovery of the wet periods from the droughts was observed to be declining, post the year 2000. For most locations, 1983 recorded the most intense drought, while a few others like Navrongo and Wa also saw 2015 being hard-hit by another. Aridity in the study area was found to be intensifying, with aridity index values increasing at a rate of 0.2/decade, although this was not found to be significant (p-value = 0.06) at a 0.05 level of significance. Similar to rainfall, aridity for most of the stations appeared to be increasing although these changes were not statistically significant, except for Wenchi, which again recorded a significant increase (p-value of 0.02).

Journal	Title & Author(s)	Abstract
Heliyon. 2019 **Apr; 5(4): e01492**	*Smallholder farmers' livelihood adaptation to climate variability and ecological changes in the savannah agro ecological zone of Ghana* Philip Aniah, Millar Katherine Kaunza-Nu-Dem, and Joseph A. Ayembilla	Climate variability and ecological changes have consequently altered life and natural livelihood-sustaining systems, leading to socio-cultural, economic and environmental challenges and vulnerabilities. The risk factors are very high, and the impacts will raise the developmental impediments of safeguarding livelihood security and poverty eradication in Sub-Saharan Africa. Adaptation to climate and ecological variation, though recognized as pressing and necessary, operates in the context of numerous uncertainties and unknowns. Previous studies on climate adaptation tried to identify universal patterns of coping, rather than differentiating between agroecological zones, villages and types of households. This paper uses case studies from two rural communities in the savannah agro-ecological zone of Ghana, to explore smallholder farmers' responses to climate and ecological variation effects on their livelihood activities that have emerged since the mid-1980s. Results suggest that smallholder farmers use various coping, on-farm and off-farm adaptation strategies, to ameliorate the negative impacts of climate and ecological changes on their livelihood. Coping measures such as selling household assets, migration of the entire households, and decreasing food consumption/changing diets, can be damaging. On-farm adaptation strategies such as varying planting dates, use of drought tolerant crop varieties, and soil conservation strategies, are based on farmers' indigenous knowledge passed down through generations. To ensure sustainability of local adaptation strategies, there is the need for an exchange of knowledge between and among smallholder farmers and formal institutions, through the recognition and empowerment of local residents and collective actions.
Journal of Disaster Research Vol.9 No.4, 2014	*Dry Spells Occurrence in Tamale, Northern Ghana – Review of Available Information* Gordana Kranjac-Berisavljevic, Shayibu Abdul-Ghanyu,Bizoola Zinzoola Gandaa, and Felix K. Abagale	Sustainable crop production is important for food security in Northern Ghana, where highly variable rainfall coupled with high evaporation rates and soils prone to degradation combine to produce low crop yields of main staple crops that are vital for local people's livelihoods. Rainfall in this region generally ranges between 800 mm and 1200 mm per annum, falling within a single rainy season from April to October, with a peak in late August-September. This amount is adequate for most arable crops such as maize, rainfed rice, soybeans, and yams. Intermittent dry spells occur, however, at critical crop growth stages, resulting in significant yield reductions. Several studies conducted in this area show that dry spells can be expected during each annual rain season, with a high level of certainty and duration from two to three days up to four weeks. This paper reviews both available literature on dry spell incidence and rainfall prediction in the West African region, with a particular focus on northern Ghana. Available daily rainfall data for 52 consecutive years are analysed to determine dry spell duration and occurrence in northern Ghana.

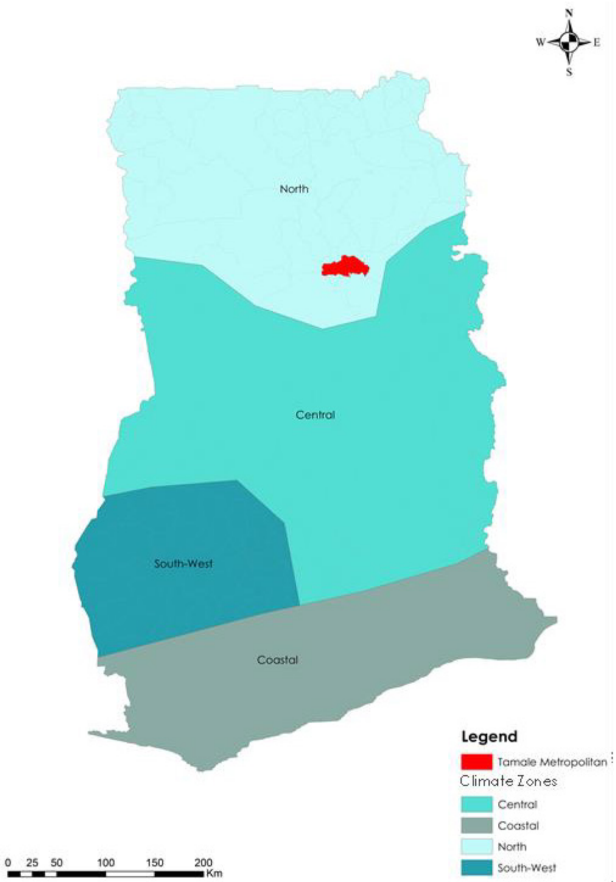
Journal	Title & Author(s)	Abstract
Sustainability Science, 2009 **Jan; 5(1):89-97**	*Drought frequency in the Volta Basin of West Africa* Raymond Kasei, Bernd Diekkrüger, & Constanze Leemhuis,	According to various reports, climate change is responsible for the change in rainfall amount and pattern, accompanied by the various degrees of extreme events in Sahelian West Africa in recent years. Other reports also suggest that there has been a "recovery" of the rainy season (Nicholson 2005). In this study, temporal characteristics of meteorological droughts in the Volta Basin, a semi-arid region in West Africa, are investigated in order to provide a guide for sustainable water resource management. For this purpose, drought intensity, areal extent, and recurrence frequency, is analysed using the standardised precipitation index (SPI) for a time series between 1961 and 2005 from 52 meteorology stations across the Volta Basin. Using this analysis, the severity of the historical droughts of 1961, 1970, 1983, 1992 and 2001 that occurred in the region are assessed, and their intensity, areal extent and return periods, are obtained. The drought intensity is lower than –2.0 over nearly 75% of the region, meaning that a major part of the region was under extreme drought conditions during this year. The drought of 1983/1984 has a probability of occurrence of up to 0.1 from records spanning 44 years. The areal extent of extreme drought conditions is about 90% during this drought period.

6.4 Future Climate Change Projections

For the analysis of future climate change scenarios, the country was separated into four homogenous climate zones, that are characterised by a relative homogeneity of climate in terms of its interannual variability – North, Central, South-west and Coastal. These four homogenous climate zones were identified through the analysis of trends in observed climate data, as well as similarity in the expect changes due to climate change. As a result, they are expected to respond in a similar way to future climate change, under the different global emission scenarios, which can then be translated to expected changes at the level of individual MMDAs or for individual eco-region.

Figure 22 shows the four climate zones identified for Ghana, showing that TaMA is located in the Northern Climate Zone.

Figure 22 I Four climate zones defined for synthesizing climate change projections in Ghana



6.4.1 Self-Organising Maps (SOMs) Analysis for Northern Region

As part of the Climate Scenarios Analysis Report for Ghana (see separate report), individual climate scenarios were identified for each of the four regions of Ghana, based on using Self Organising Maps (SOMs). Based on the results of the SOMs analysis, representative climate scenarios have been identified for each of the four climate zones in Ghana under three global emission scenarios: RCP2.6, RCP4.5 and RCP8.5. Out of the possible 64 representative pathways, 16 have been identified that represent multiple future scenarios and across the different zones.

The likelihood of each of these pathways has been determined based on the SOMs analysis. In addition, an Upper Extreme (UE) and Lower Extreme (LE) pathway have also been identified.

For each representative pathway, a single representative climate model/scenario combination has been identified from the CORDEX dataset, which can then be used to provide additional information on specific climate variables for further study. Table 7, Table 8 and Table 9 show the results of joint pathways analysis for the Northern Climate Zone under RCP2.6, RCP4.5 and RCP8.5, respectively.

Table 7 I Results of joint pathways analysis for the Northern Climate Zone under RCP2.6

Scenario	Likelihood of Individual Scenarios	Expected Impacts Temperature (°C) / Rainfall (ratio)		
	North	2035	2055	2075
A26	1 35%	0.5/1.05	0.5/1.05	0.5/1.05

B26	2 25%	1.5/1.05	1.5/1.05	2.0/1.05
C26	3 25%	1.0/1.00	1.0/1.00	1.0/1.00
D26	4 15%	1.0/0.95	1.5/0.95	1.0/0.95
UE A26	□	0.5/1.15	1.0/1.15	1.5/1.10
LE A26	□	1.0/0.95	1.0/0.95	1.5/0.90

Table 8 I Results of joint pathways analysis for the Northern Climate Zone under RCP4.5

Scenario	Likelihood of Individual Scenarios	Expected Impacts Temperature (°C) / Rainfall (ratio)		
	North	**2035**	**2055**	**2075**
A45	1 50%	0.5/1.05	1.0/1.00	1.5/1.00
B45	□	1.5/1.05	1.0/1.00	1.5/1.05
C45	2 40%	1.0/1.00	1.0/0.95	1.5/0.95
D45	3 10%	1.0/0.95	1.0/1.10	1.5/1.10
UE A45	□	0.5/1.15	1.0/1.15	1.0/1.15
LE A45	□	1.0/0.95	1.0/0.90	2.0/0.90

Table 9 I Results of joint pathways analysis for the Northern Climate Zone under RCP8.5

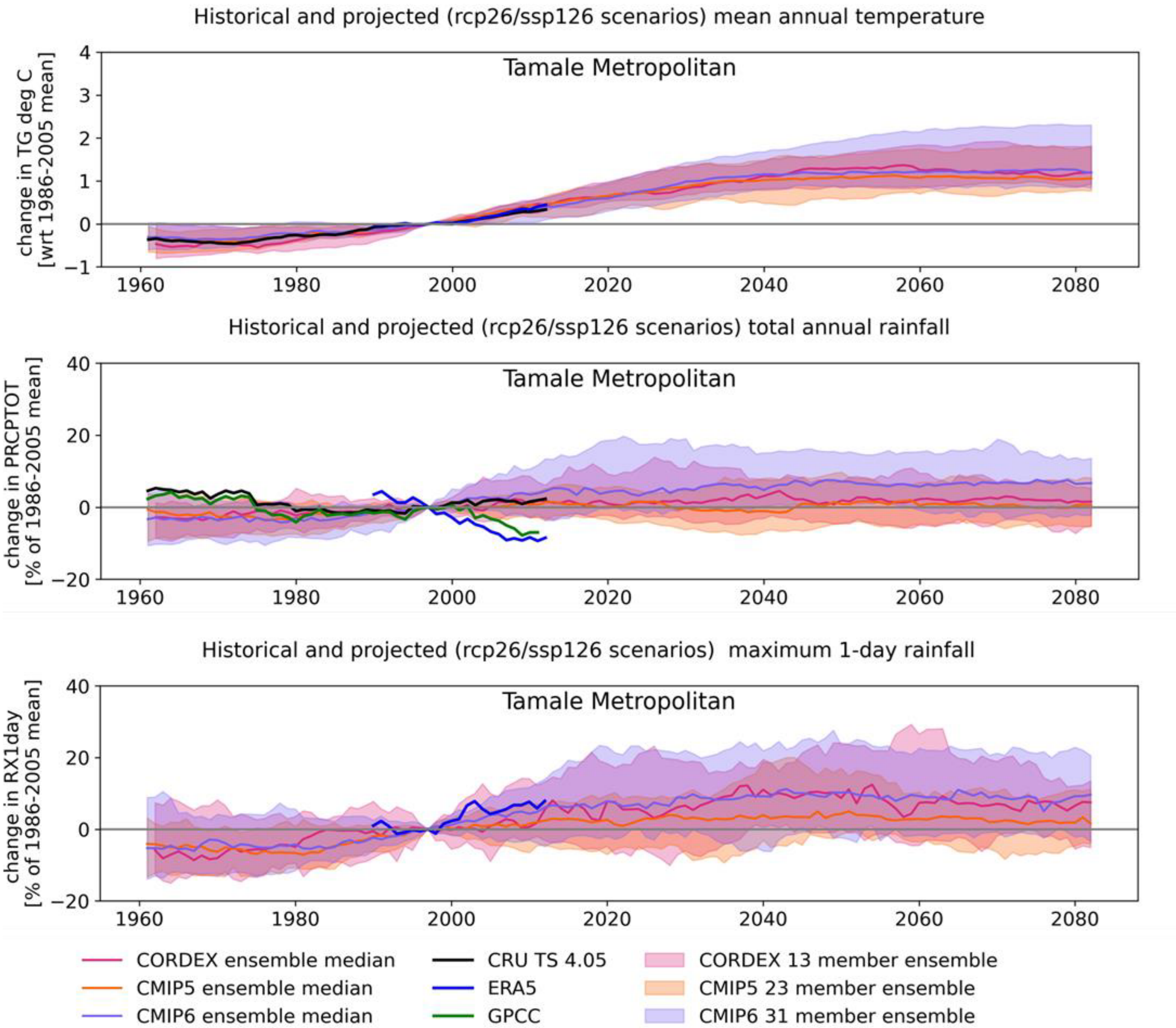
Scenario	Likelihood of Individual Scenarios	Expected Impacts Temperature (°C) / Rainfall (ratio)		
	North	2035	2055	2075
A85	1 40%	1.0/1.05	2.0/1.05	3.5/1.05
B85	**2 35%**	1.5/0.95	2.5/0.95	4.5/0.90
C85	□	1.5/1.00	2.5/1.00	3.5/1.00
D85	3 25%	1.5/1.10	2.0/1.10	3.5/1.15
UE A85	□	1.0/1.10	2.0/1.15	3.5/1.20
LE A85	□	1.0/0.90	3.5/0.90	5.0/0.85

6.4.2 Plume Plots Analysis for TaMA

In addition to the SOMS analysis, individual plume plots showing the range of potential impacts on key climate variables (i.e., temperature, precipitation and maximum daily rainfall), were also produced for each of the selected MMDAs that also show how the future climate scenarios evolve over time.

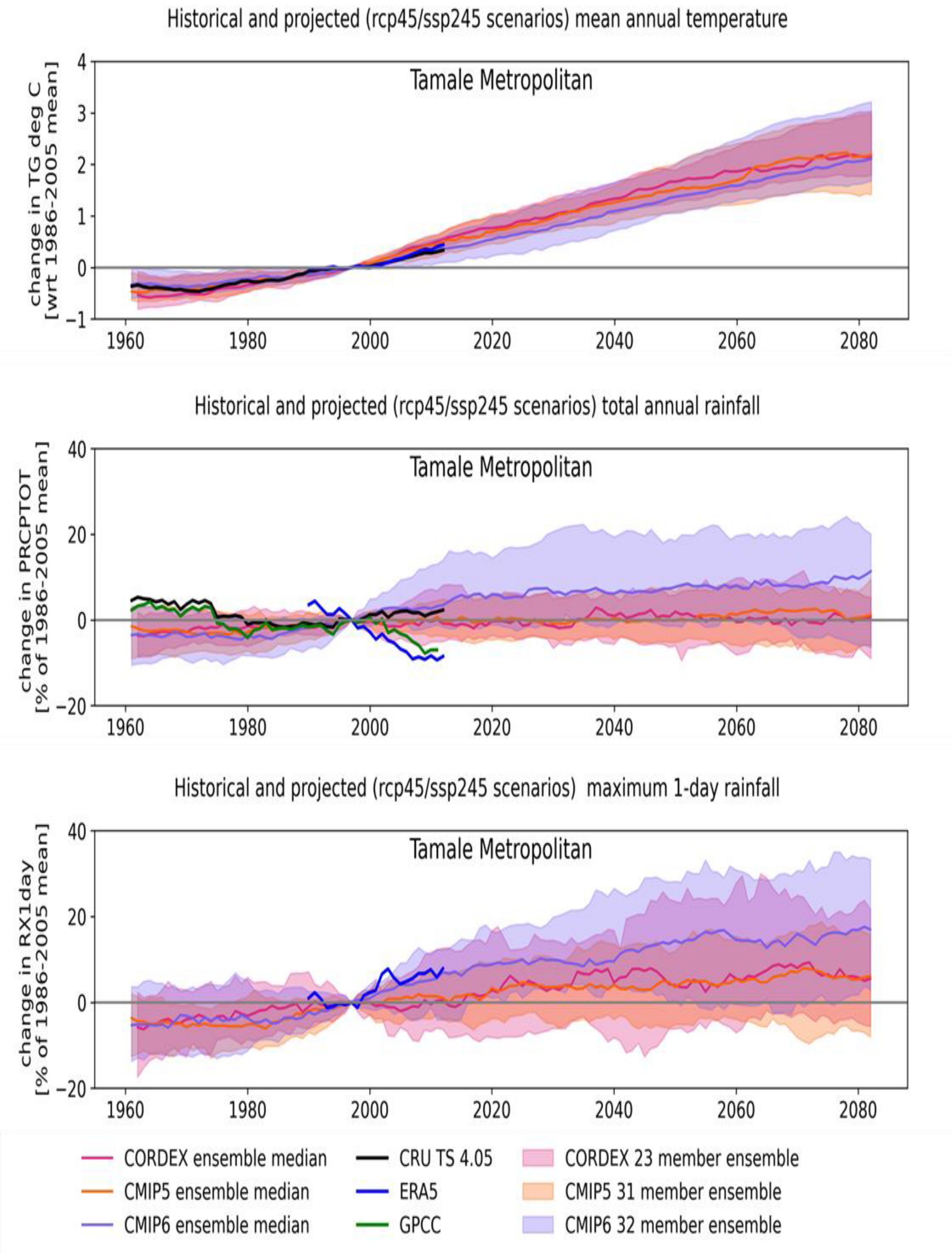
The plume plots showing the range of possible climate scenarios derived from both the CMIP5 and CMIP6 ensemble of climate models, as well as the CORDEX dataset of downscaled climate scenarios (CMIP5 only) for Tamale, are shown in Figure 23, Figure 24 and Figure 25**.** These represent the combined global emission scenarios of SSP1-2.6, SSP2-4.5 and SSP5-8.5, respectively. The individual plume plots show the median and 10th and 90th percentile values for: (1) change in average daily temperature, (2) change in mean annual precipitation, and (3), change in the maximum one-day rainfall up to 2100. The plots also show the observed historical climate data from multiple sources.

Figure 23 | Plume plots illustrating the evolution of mean annual temperature, total annual rainfall and maximum 1-day rainfall in TaMA, for simulations of historical and future climate in three ensembles under RCP2.6/SSP1-2.6 scenarios



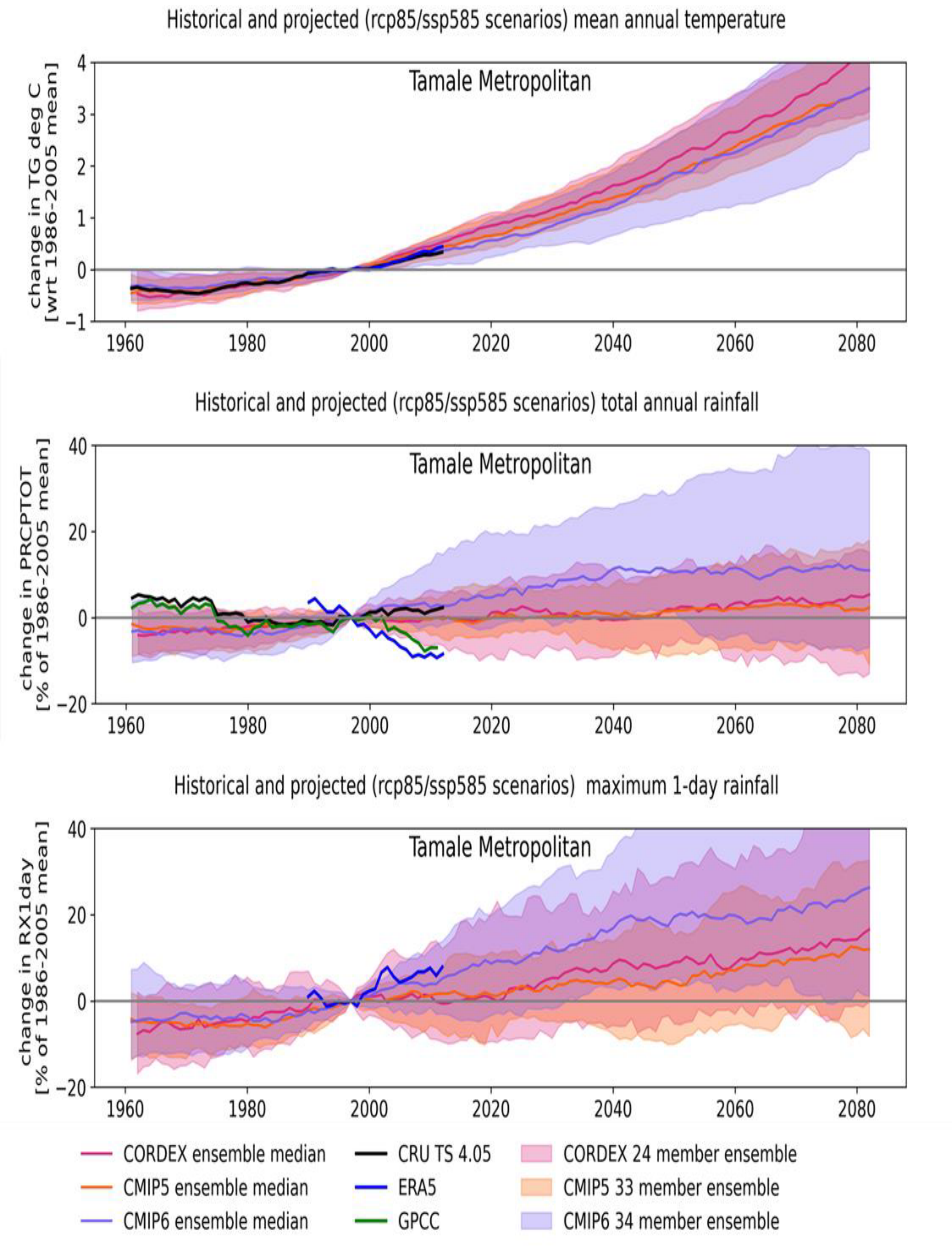
Note: All lines represent 20-year running averages calculated on annual values

Figure 24 | Plume plots illustrating the evolution of mean annual temperature, total annual rainfall and maximum 1-day rainfall in TaMA, for simulations of historical and future climate in three ensembles under RCP4.5/SSP2-4.5 scenarios



Note: All lines represent 20-year running averages calculated on annual values

Figure 25 | Plume plots illustrating the evolution of mean annual temperature, total annual rainfall and maximum 1-day rainfall in TaMA, for simulations of historical and future climate in three ensembles under RCP8.5/SSP5-8.5 scenarios



Note: All lines represent 20-year running averages calculated on annual values

6.5 Downscaled Climate Change Scenarios

The overall messages about future climate scenarios in Ghana, emerging from the analyses, are as follows:

- **A strong confidence** message of **increases in air temperatures** manifested in all scenarios and in all four climate zones identified for Ghana. These increases amount to **0.5 to 1.5°C, 1.5 to 2.5°C** and **2.5 to 4.5°C** above historical mean at the end of the 21st century under **RCP2.6/SSP1-2.6, RCP4.5/SSP2-4.5** and **RCP8.5/SSP5-8.5** respectively. These will be higher in the inland regions.
- **A moderate to low confidence** message of **weak changes (+/- 5%)** (comparable to, or only slightly stronger, than the level of variability simulated for the past) in the overall **"wetness"** of the climate, **without a clearly defined direction** of future changes in total annual rainfall, independent of emission scenario. This **low confidence** is partly caused by the lack of consistency in historical rainfall trends between observational data and model simulations.

The expected change in critical climate variables for each of the selected climate scenarios and models for the different emission scenarios and the representative SOMS analysis, is shown in Table 10.

The expected likelihood of the scenarios for the Northern Climate Zone is included in the table.

Table 10 I Change in critical climate variables for TaMA relative to the base period for the representative climate models, representing the different future climate scenarios and the SOMs analysis

Period		2030-2040						2050-2060						2070-2080					
Climate Model		A	B	C	D	LE	UE	*A*	*B*	*C*	*D*	*LE*	*UE*	A	B	C	D	LE	UE
Climate variable	Baseline 1960-2000																		
RCP 2.6																			
Likelihood*		35%	25%	25%	15%	□ (A)	□ (A)	*35%*	*25%*	*25%*	*15%*	*□ (A)*	*□ (A)*	35%	25%	25%	15%	□ (A)	□ (A)
TG	27.6	2%	4%	4%	4%	4%	3%	*1%*	*5%*	*4%*	*4%*	*4%*	*5%*	3%	6%	3%	3%	4%	5%
TXx	36.3	1%	3%	3%	3%	3%	2%	*1%*	*4%*	*4%*	*4%*	*3%*	*4%*	2%	5%	2%	2%	4%	4%
SU30	29	-1%	5%	7%	7%	10%	2%	*-1%*	*7%*	*7%*	*7%*	*12%*	*5%*	1%	7%	4%	4%	11%	4%
PRCPTOT	87	-2%	7%	-6%	-6%	-3%	9%	*-4%*	*8%*	*0%*	*0%*	*-6%*	*12%*	-6%	4%	8%	8%	-7%	6%
Rx1day	13	-36%	140%	-7%	-7%	-39%	56%	*-22%*	*141%*	*37%*	*37%*	*-44%*	*179%*	-17%	114%	224%	224%	-25%	115%
RCP 4.5																			
Likelihood*		50%	□	40%	10%	□ (A)	□ (A)	*50%*	□	*40%*	*10%*	*□ (A)*	*□ (A)*	50%	□	40%	10%	□ (A)	□ (A)
TG	27.6	2%	□	4%	4%	4%	3%	1%	□	4%	4%	4%	5%	3%	□	3%	3%	4%	5%
TXx	36.3	3%	□	3%	3%	6%	3%	*3%*	□	*4%*	*6%*	*8%*	*6%*	6%	□	5%	6%	7%	6%
SU30	29	6%	□	1%	11%	21%	11%	*8%*	□	*2%*	*18%*	*24%*	*18%*	10%	□	3%	18%	24%	18%
PRCPTOT	87	-1%	□	-1%	-13%	-21%	-13%	*-1%*	□	*-8%*	*-16%*	*-14%*	*-16%*	-5%	□	0%	-9%	-15%	-9%
Rx1day	13	4%	□	-43%	-166%	-60%	-166%	*6%*	□	*25%*	*-80%*	*-13%*	*-80%*	-44%	□	1%	60%	3%	60%
RCP 8.5																			
Likelihood*		40%	35%	□	25%	□ (A)	□ (A)	*40%*	*35%*	□	*25%*	*□ (A)*	*□ (A)*	40%	35%	□	25%	□ (A)	□ (A)
TG	27.6	3%	4%	□	5%	5%	3%	*4%*	*8%*	□	*8%*	*10%*	*4%*	9%	12%	□	12%	15%	9%
TXx	36.3	2%	3%	□	3%	4%	2%	*3%*	*6%*	□	*5%*	*9%*	*3%*	7%	10%	□	8%	14%	7%
SU30	29	0%	12%	□	8%	7%	0%	*-1%*	*16%*	□	*10%*	*12%*	*-1%*	1%	20%	□	15%	15%	1%
PRCPTOT	87	-1%	-7%	□	6%	27%	-1%	*7%*	*-5%*	□	*22%*	*8%*	*7%*	0%	-3%	□	6%	-8%	0%

Rx1day	13	100%	-81%	□	78%	288%	100%	*108%*	*60%*	□	*120%*	*219%*	*108%*	20%	22%	□	70%	30%	20%

* *Likelihood of Individual Scenarios for the Northern Climate Zone, based on the SOMs analysis

TG - Daily Mean Temperature; TXx - Maximum temperature; SU30 - Hot days with a maximum above 30ºC (SU30), PRCPTOT - Total Annual Precipitation; Rx1day - Maximum 1-day total precipitation

In general, the latest **CMIP6 model results (**Table 11**)** suggest **greater climate sensitivity** and the potential for more **significant "wetting"**, particularly over the Northern Climate Zone, but **further analysis is required** to clarify these results. Temperature is expected to increase significantly for Tamale, with the greatest increases in temperature being as a result of the higher global emission scenarios.

Table 11 I Change in critical climate variables for TaMA relative to the base period for the different future climate scenarios (CMIP6)

Period		2030-2040			2050-2060			2070-2080		
Climate variable	Baseline 1960-2000	Q90	Q50	Q10	Q90	Q50	Q10	Q90	Q50	Q10
RCP 2.6										
TG	27.6	3%	4%	6%	3%	4%	8%	3%	4%	8%
TXx	36.3	1%	3%	5%	2%	4%	7%	2%	4%	7%
SU30	29	2%	4%	13%	2%	6%	16%	2%	6%	15%
PRCPTOT	87	-4%	5%	18%	-1%	7%	21%	-5%	6%	18%
Rx1day	13	-46%	44%	200%	-18%	44%	190%	-27%	46%	171%
RCP 4.5										
TG	27.6	2%	3%	5%	4%	5%	9%	5%	7%	11%
TXx	36.3	1%	3%	5%	2%	4%	7%	3%	6%	9%
SU30	29	0%	4%	12%	2%	7%	22%	4%	8%	27%
PRCPTOT	87	-1%	9%	23%	-4%	10%	25%	-10%	10%	30%
Rx1day	13	16%	59%	218%	-33%	109%	240%	2%	140%	249%
RCP 8.5										
TG	27.6	2%	4%	6%	4%	7%	11%	7%	12%	18%
TXx	36.3	1%	3%	5%	2%	6%	10%	3%	10%	14%
SU30	29	0%	4%	13%	3%	6%	26%	3%	11%	31%
PRCPTOT	87	-1%	11%	26%	0%	11%	36%	-6%	11%	46%
Rx1day	13	15%	107%	262%	23%	160%	342%	12%	190%	538%

TG - Daily Mean Temperature; TXx - Maximum temperature; SU30 - Hot days with a maximum above 30ºC (SU30), PRCPTOT - Total Annual Precipitation; Rx1day - Maximum 1-day total precipitation

6.5.1 Temperature

In the future, there is a greater likelihood for more significant increases in **temperature** in the Northern Climate Zone (and the Central) than in the other two climate zones identified for Ghana. Temperatures are projected to increase under RCP2.6 and tend to plateau after mid-century. There is also some plateauing in the final two decades under RCP4.5, but under RCP8.5, temperatures are expected to increase throughout the century, reaching an average rise of almost 4ºC by the end of the century. By mid- century, Tamale will see a **temperature** increase of between 1.18°C and 2.24°C under RCP4.5, and between 1.67°C and 2.95°C under RCP8.5. The rise in temperatures will likely be steeper towards the end of the century, with increases between 1.5°C under RCP2.6 and 3.5/4°C under RCP8.5, with RCP4.5 suggesting a mid-point of about 2.0°C, for the selected scenarios based on the SOMS analysis.

6.5.2 Extreme Heat

Extreme heat is defined as the hot days with a maximum above 30ºC (SU30). Tamale is the northern city, and is generally hot and dry throughout the year. The average temperature in Tamale is around 29°C, with the hottest months being those between March and May. However, the extreme heat events are becoming more frequent and intense in Ghana, due to climate change, and Tamale is no exception. Under RCP4.5, all models projected a significant increase in the number of days exceeding 30°C in Tamale by 2050s and 2100, while some of the models (A and UE-Models) under RCP8.5 projected a decrease of 1%. The City is expected to experience an increase of between 2% and 24% under RCP4.5 by the 2050s.

By 2100, this change is expected to be within the range of 3% and 24%, relative to the baseline.

6.5.3 Precipitation

Precipitation does not vary as much as for other regions in Africa. There is a slightly greater chance of **small increases** in annual average precipitation compared to the base years, typically around a 5% increase. There is also a relatively significant chance of **decreases** in precipitation to a similar degree. The extremes suggest that a change in precipitation of up to +/-15/20% is possible.

The plume plots suggest there is a relatively good match in the precipitation scenarios and that the scenarios do a relatively good job of capturing the possible variation at RCP2.6, but not at RCP4.5 or RCP8.5, where there is a chance of significant increases in rainfall, possibly up to 20%, by the end of the century.

Precipitation will remain highly variable by the mid-century, but there is a possible change of -15% to 20%, relative to the baseline. The CMIP6 models suggest a much greater chance of wetting for Tamale and across the Northern Climate Region of Ghana, although this does require further investigation.

6.5.4 Extreme Rainfall

Maximum daily rainfall is expected to increase under all scenarios, but particularly under CMIP6, with the greatest increase in maximum daily rainfall occurring under SSP5-8.5. Under this scenario, the median value for the increase in maximum daily rainfall is around 20% by 2050, but could be as high as a >40% increase.

Heavy precipitation events become more likely in the future, especially under the high emission scenario. This will have a significant impact on the potential for increased flooding events in Tamale.

7

Potential Impacts for Priority Risk Domains

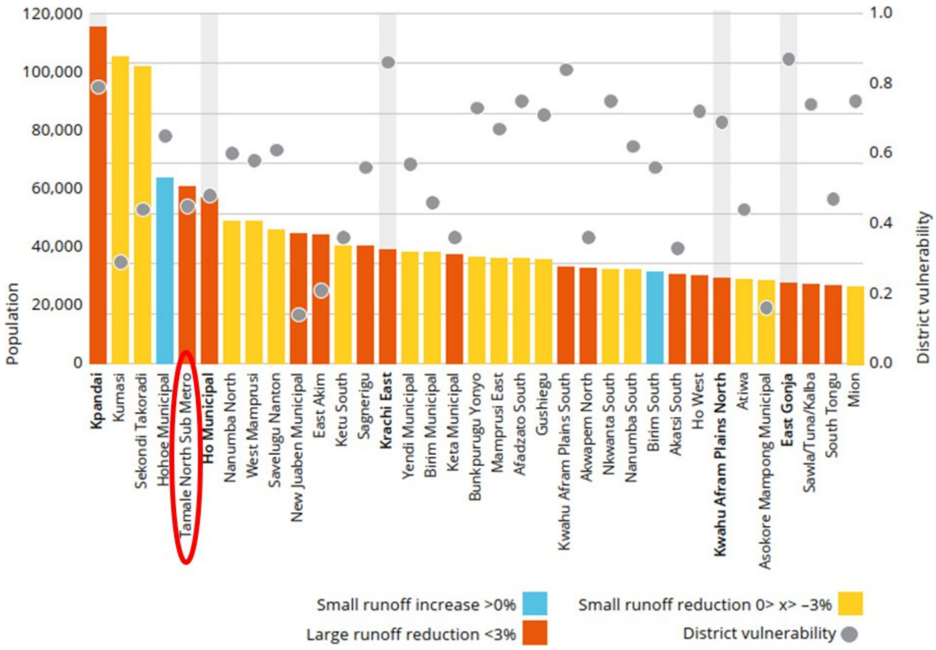
The potential impact of climate change on the priority risk domains are described here, and include:

- Water Resources (surface and groundwater)
- Inland Flooding (pluvial and fluvial)
- Drought
- Wildfires
- Water Security and Supply
- Agriculture: Crop and Livestock Probability
- Human Health

7.1 Water Resources

Climate change is expected to contribute to a reduction in runoff for the northern parts of Ghana, including the area around Tamale Metropolis. This is largely due to increased variability in rainfall and higher temperatures. Even with a potential increase in the likelihood of wetter climate scenarios, higher temperatures and associated increases in evapotranspiration will likely result in an overall reduction in runoff, except during periods of very high flow, which will result in an increased risk of flooding.

Figure 26 I Climate change risk for water resource availability for selected MMDAs



Source: (Ghana: Roadmap for resilient infrastructure in a changing climate, 2022)

More variable rainfall, on its own, will also contribute to an overall reduction in the availability of surface water (and potentially also groundwater), particularly if there is limited available storage capacity. As more intense rainfall increases, surface runoff also increases, contributing to erosion of the topsoil and sedimentation in the riverbeds. Reduced rainfall could limit ground water recharge and exacerbate saline intrusion, as well as reduce vegetation cover. Additionally, reduced rainfall could also reduce the dilution of contamination/pollution in the rivers, thereby worsening water quality.

Severe degradation of the river due to land clearing and unsustainable agricultural practices, sand mining, overgrazing, fuelwood harvesting and charcoal production, driven by population growth and a changing climate, is not only threatening water supply, but also biological diversity in the White Volta Basin (Awotwi, Yeboah, & Kumi, 2014) (Nsor, Ashiagbor, & Danquah, 2019) (Abu & Peprah, 2020) (Tahiru, Doke, & Baatuuwie, 2020) (Arends, 2021). As a result of vegetation clearing for agriculture and settlements, and sand mining in the river channel and floodplain, water is becoming contaminated with sediments and pollutants, and dry season water flows are decreasing (Kumordzi, 2020). Recent studies have demonstrated the sensitivity of river flows and water quality of the White Volta River to changes in land cover and land use in the basin (Awotwi, Yeboah, & Kumi, 2014) (Tahiru, Doke, & Baatuuwie, 2020).

It has been found that land cover transformation (involving the loss of natural vegetation) corresponded to a decrease in surface water and base flow (Awotwi et al., 2014), as well as an increase in the levels of turbidity and ammonia over a period of ten years (2007-2017); (Tahiru, Doke, & Baatuuwie, 2020). The diminishing water quality significantly increases water treatment costs, and the decreasing dry season flows have an impact on the quantity of water available for abstraction. Increased protection of the vegetation and soils of the Nawuni catchment is essential in ensuring water security and avoiding elevated water treatment costs (Anchor Environmental Consultants, South Africa, 2022).

7.2 Flooding

Floods are dominated by two aspects: 1) the presence of excessive water, and 2) the topographical characteristics of the area. The phenomenon of urban floods is caused by the effects of deficient or improper land use planning. Many urban areas facing the challenges of increased urbanization, coupled with increasing populations, and high demands for land, do not properly enforce legislations aimed at mitigating against floods. Understanding flood risk requires knowledge of the different types of floods, their probabilities of occurrence, how they can be modelled and mapped, what the required data are for producing hazard maps, and the possible data sources for these (Jha, et al., 2012).

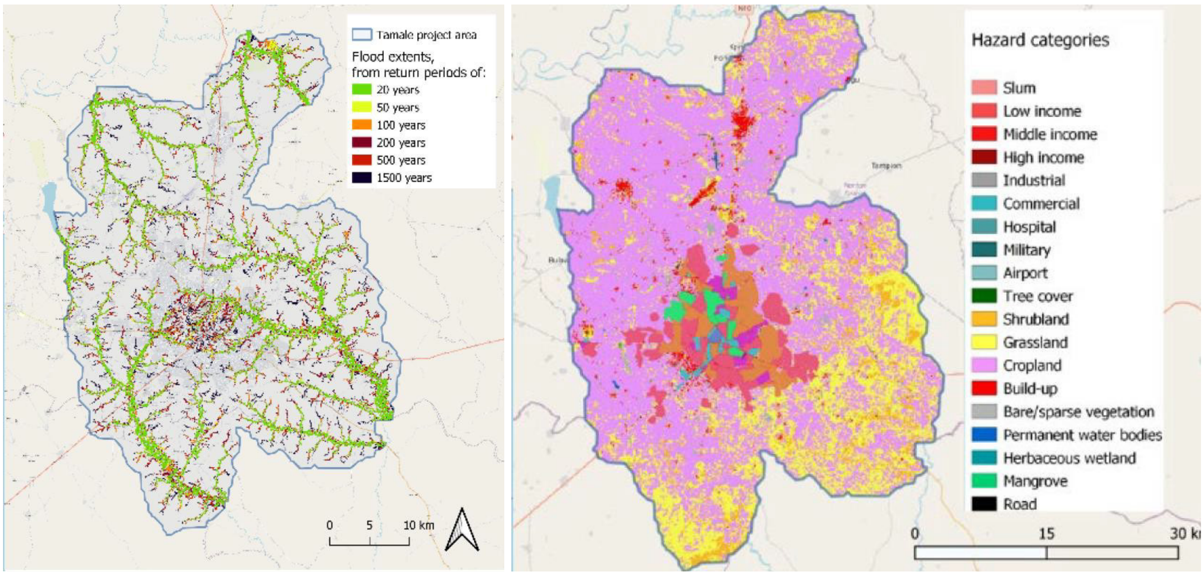
The natural topographic characteristics of Tamale City, being relatively flat but built upon a raised area, with the rest of the City lower-lying, combined with the hydro-meteorological conditions of the region, are causal factors for the urban floods in Tamale. However, these are exacerbated by the rapid ‘unplanned’ urbanization, resulting in the encroachment on natural drainage systems and drains.

A high-level assessment of the flood hazards, damage and risks in Tamale, using a flood risk mapping and modelling approach, was undertaken in 2022 with the aim of improving the evidence-based information on urban flooding, to support the planning and implementation of solutions to alleviate flood risk. The project area for this project was determined by assessing the extent of the built-up urban area and selecting the river basins to include those urban areas, which resulted in a bigger area than TaMA.

This study defined flood risk as “*a combination of the probability (likelihood or chance) of a flood event (or flood hazard) happening and the consequences (impact) if it occurs*” (Triple Line Consulting Limited, 2022). The flood risk assessment was done by combining flood hazard information for different return periods, land-use data (Figure 27), and flood damage curves (showing to what extent a maximum damage is reached depending on the flood depth) for each land-use type, and maximum damage values for each land-use type. These were then combined to determine an Average Expected Damage (AED) function for Tamale (Table 12). The flood hazard maps were also cross-checked against the presence of streams and drains that could be identified from satellite images.

From these, it was concluded that, in general, the hazard maps represent the position of streams and drains, but with some deviations. This is especially the case in Tamale, likely caused by limitations in the accuracy of the elevation defined for the Tamale region. Tamale is relatively flat, deviating approximately 15-20 m across the project area, at an average slope of only around 1 degree.

Figure 27 I Flood hazard and land use maps for the Flood Risk Mapping and Modelling study area in Tamale



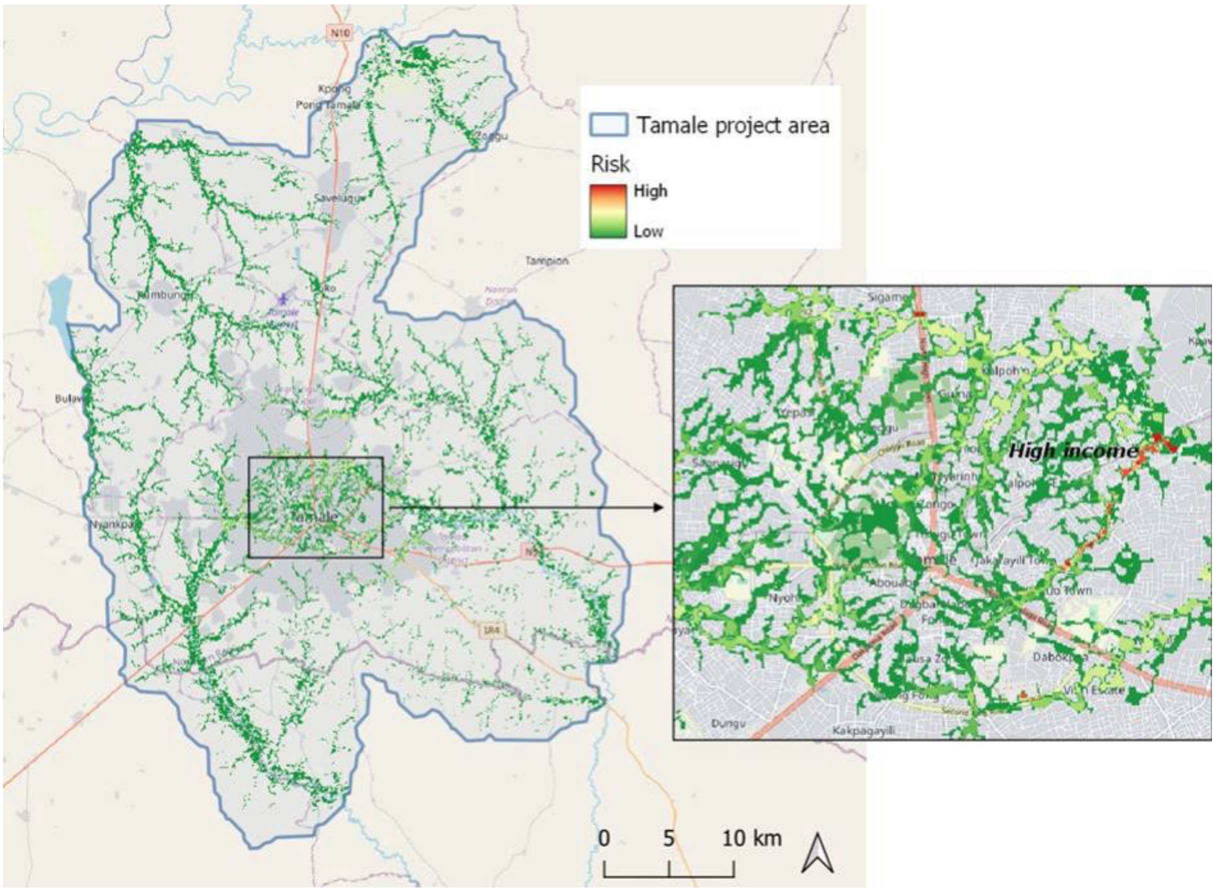
Source: (Triple Line Consulting Limited, 2022)

Table 12 I Flood damage and risk for Tamale for various return periods of floods

Damage caused by fluvial flooding Tamale (USD millions)													
Return period	Slum	Low income	Middle income	High income	Industrial	Commercial	Hospital	Military	Airport	Cropland	Build-up	Roads	Total
T20	-	274.4	228.1	56.8	-	3.2	-	-	-	31.8	1.7	2.6	599
T50	-	387.1	321.1	81.1	-	21.9	-	-	-	38.7	2.5	3.2	856
T100	-	504.7	390.8	109.6	-	53.9	-	-	-	44.7	3.2	4.0	1,111
T200	-	609.7	475.8	155.3	-	95.0	-	-	-	51.2	4.1	5.0	1,396
T500	-	812.1	638.3	233.4	-	205.3	1.6	-	-	62.0	6.2	6.8	1,966
T1500	-	1,153.5	906.6	342.2	-	318.1	2.7	-	-	80.4	10.1	10.1	2,824
AED	-	21.4	17.3	4.9	-	2.1	0.0	-	-	2.0	0.1	0.2	48
AED % of total	-	45%	36%	10%	0%	4%	0%	0%	0%	4%	0%	0%	100%

The maps below present the spatial representation of the flood hazard areas for Tamale. From this it can be concluded that, in Tamale, increased flood risk occurs across the entire project area. High risk areas in Tamale are mainly mixed-income residential areas inside these original floodplains, possibly better described as flood paths. These areas should be prioritised when developing flood mitigation measures. However, as indicated, risks calculated for Tamale are likely overestimated. To address these inaccuracies, the flood hazard model data and land-use data should be further improved.

Figure 28 l Flood risk map of Tamale



Source: (Triple Line Consulting Limited, 2022)

To calculate the future risk, the return periods of rainfall events were recalculated (assuming similar effect on the likelihood of flood events), assuming that the daily maximum rainfall will have increased by 10%. This resulted in shorter return periods in the future, as shown in Table 13. These changes in the probability of each level of flooding event were then used to determine a future AED. The study concluded that "a 10% increase in the maximum daily rainfall (due to climate change impacts) leads to a 92% increase in the AED. The environmental and social impacts of flooding would need to be assessed, and avoided costs calculated, to provide a more comprehensive estimate of the potential total avoided cost of inaction" (Triple Line Consulting Limited, 2022).

Table 13 I Effect of climate change on flood return periods

Return period current situation	Return period future situation
T = 50	T = 20
T = 20	T = 10
T = 10	T = 6
T = 5	T = 4

Source: (Triple Line Consulting Limited, 2022)

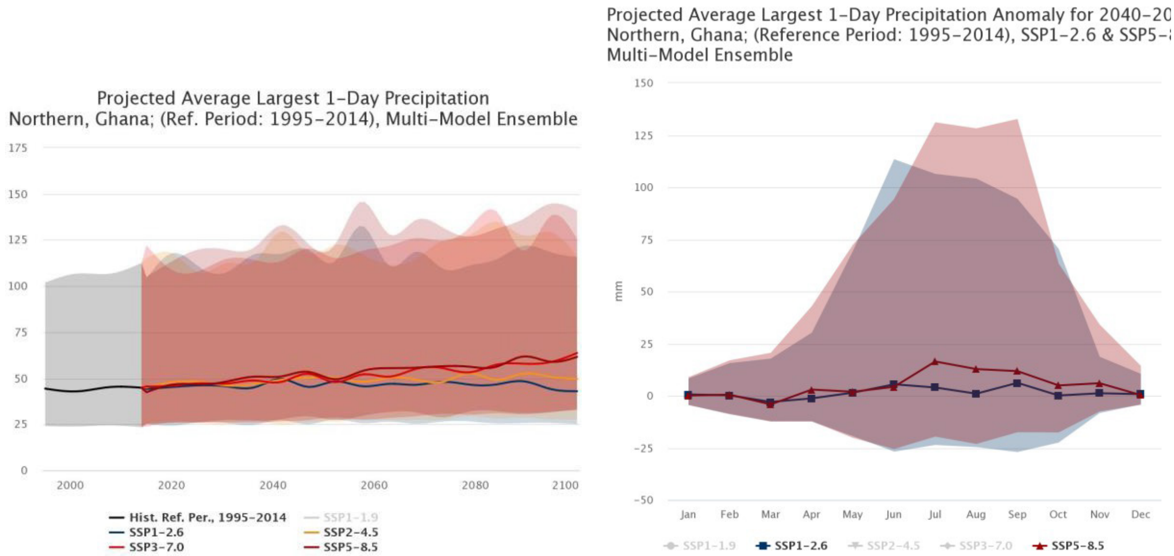
Table 14 I Climate change impact on flood damage and risk in Tamale for various return periods of floods

Damage caused by fluvial flooding Tamale (USD millions)												
Return period	Low income	Middle income	High income	Industrial	Commercial	Hospital	Military	Airport	Crops	Built-up	Roads	Total
T20	274	228	57	-	3	-	-	-	32	2	3	596
T50	387	321	81	-	22	-	-	-	39	2	3	852
T100	505	391	110	-	54	-	-	-	45	3	4	1,107
T200	610	476	155	-	95	-	-	-	51	4	5	1,391
T500	812	638	233	-	205	2	-	-	62	6	7	1,959
T1500	1,154	907	342	-	318	3	-	-	80	10	10	2,814
AED	41	33	9	0	4	0	0	0	4	0	0	92
AED % of total	20%	34%	6%	0%	19%	0%	0%	0%	18%	1%	1%	1

Source: (Triple Line Consulting Limited, 2022)

The expected change in the maximum daily rainfall under the different global emission scenarios for the Northern Region in Ghana from the CMIP6 ensemble, is shown in (Figure 29) and shows a significant increase under SSP3-7.0 and SSP5-8.5, but not under SSP2-4.5 or SSP1-2.5. The greatest impact is likely to be in July, with the median values showing an increase of around 28% in the average maximum daily rainfall, but with a range from -34% to +226% by mid-century (i.e. centred on 2050).

Figure 29 l Expected change in the Maximum Daily Rainfall for the Northern Region in Ghana



Source: Climate Change Knowledge Portal

In terms of the expected change in the frequency of extreme events, probabilistic analysis of the maximum daily rainfall suggests, on average, that the current 1 in 10-year and 1 in 100-year events could become up to 2.32 and 3.58 times more likely under SSP5-8.5 by 2050. The worst-case scenario (i.e., 90th percentile under SSP5-8.5) indicates that the 1 in 100-year event (current AEP = 1%) could become up to 13 times more likely in any year by 2050. This indicates a significant increase in the risk associated with extreme rainfall events and flooding due to climate change.

Table 15 l Expected change in Annual Exceedance Probability for Design Rainfall events for the Northern Region in Ghana by 2050 under different global emission scenarios

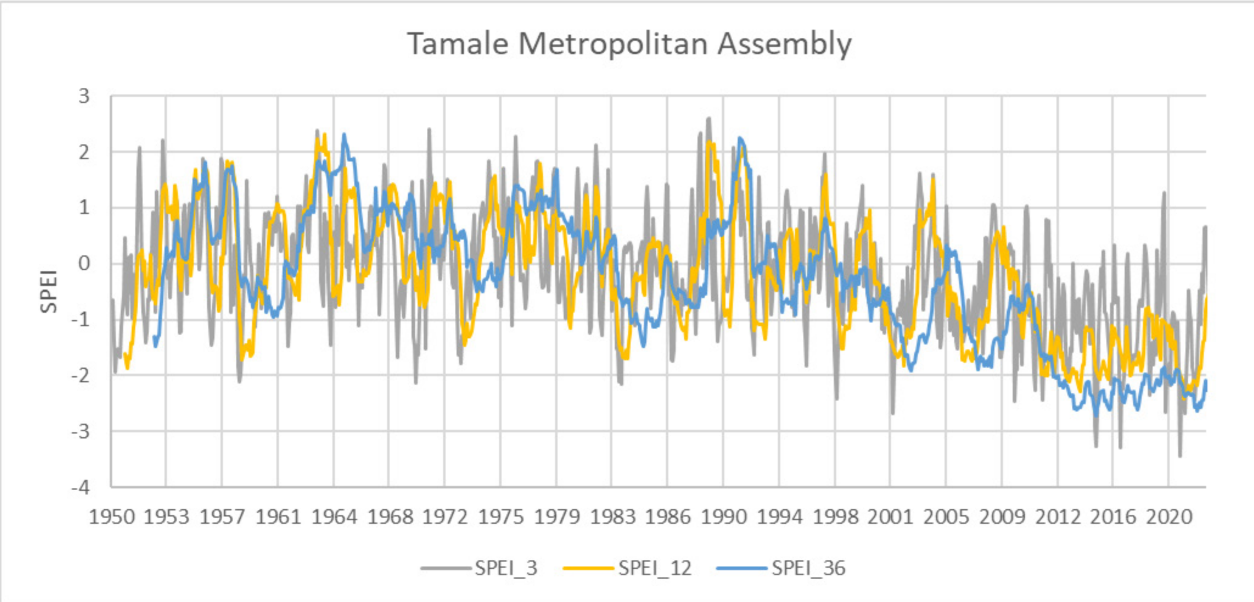
Change in Annual Exceedance Probability, 2035-2064 (centre 2050) (change factor for occurrence/ year)						
Event	**10-yr**			**100-yr**		
	10th	**median**	**90th**	**10th**	**median**	**90th**
SSP1-1.9	0.82	1.55	2.32	0.67	1.95	3.58
SSP1-2.6	0.9	1.56	2.48	0.78	1.93	4.22
SSP2-4.5	0.95	1.8	3.06	0.96	2.47	5.77
SSP3-7.0	1	1.87	3.27	0.91	2.65	6.41
SSP5-8.5	1	2.32	5.15	0.99	3.58	13.05

Source: Climate Change Knowledge Portal

7.3 Drought

Tamale already experiences significant periods of drought. The trend in the Standardized Precipitation Evapotranspiration Index (SPEI), which is a commonly used indicator of drought, shows a significant increase in drying (Figure 30). This is indicated by the negative trend in the SPEI. In particular, the cumulative 3-year (36 month) SPEI shows the increasing nature of droughts. The annual SPEI trend is much more variable, but has also been consistently low since around 2009. The seasonal (3 – month) SPEI trends show a significant increase in the variability, with both very dry, as well as very wet, periods.

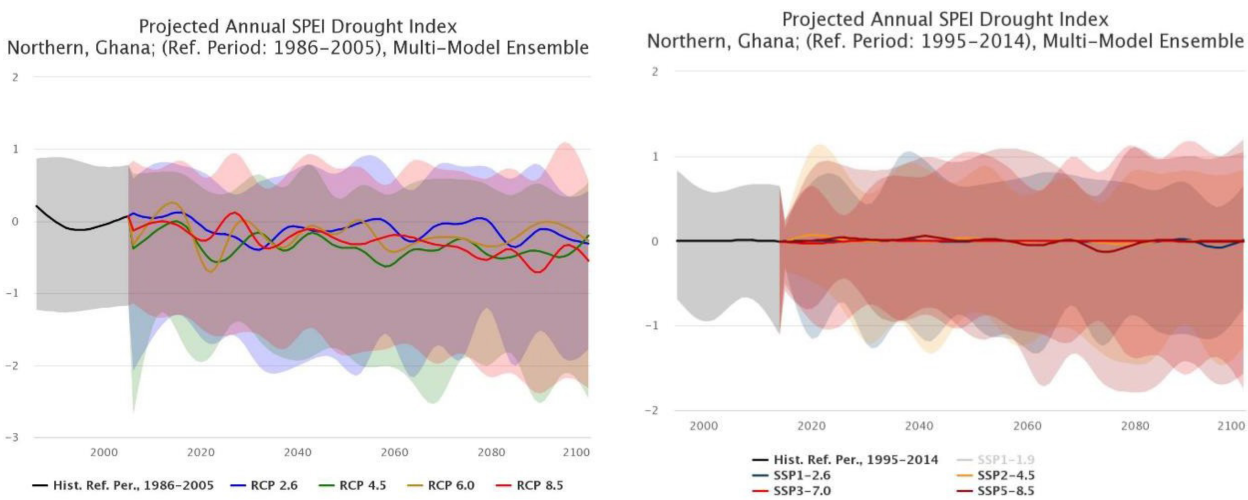
Figure 30 | Observed trends in the SPEI in TaMA, 1950-2010



Source: Data retrieved from https://spei.csic.es/database.html#p5

Previous global climate models (i.e. CMIP5) tended to show a continued decrease in SPEI, indicating a continued increasing risk of drought for the Northern Region of Tamale. The more recent global climate models (CMIP6) however, suggest that there will be no significant increase in the risk of drought, as indicated by SPEI (Figure 31). This is primarily as a result of the expected increase in precipitation indicated in the latest models, as well as a slightly lower increase in temperate, which would result in a slightly lower increase in potential evaporation. It is important to note, however, that there is a general decrease in the lower bounds of the ensemble (i.e. the lowest 10th percentile), which would suggest that there is still likely to be an increased risk of more regular and more extreme droughts in the region of Tamale.

Figure 31 | Comparison of expected impacts of climate change on annual SPEI for the Northern Region of Ghana based on the CMIP5 (left) and CMIP6 (right) full ensemble of climate models for all future emission scenarios



Source: World Bank Climate Change Knowledge Portal

7.4 Wildfires

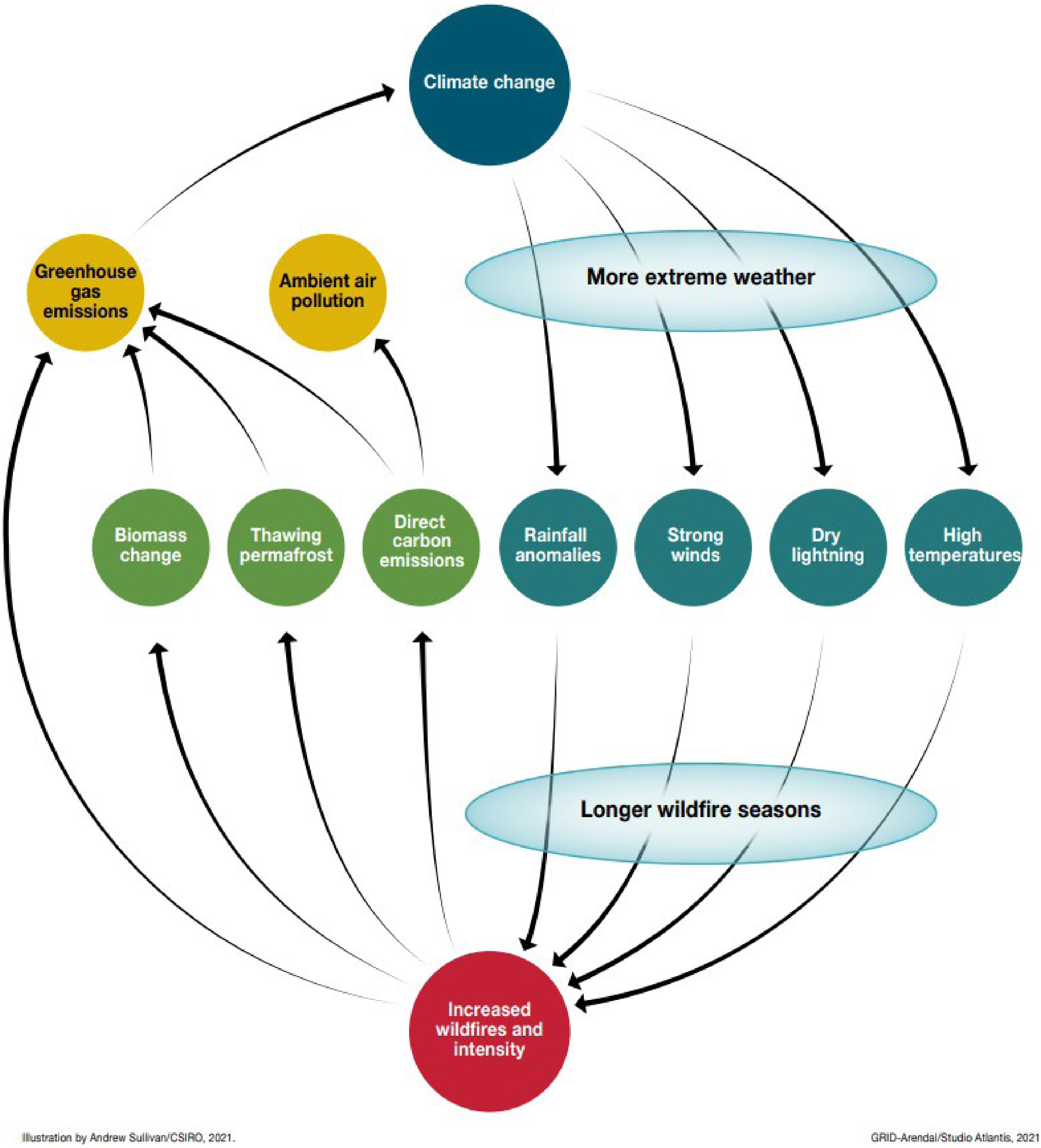
Wildfires have been identified as a problem in the catchment areas around Tamale because both the intensity and frequency of fires have increased in recent years. Wildfires are started mainly from human activities such as honey tapping and group hunting, and are more likely to occur on hot days. Hunters start fires to flush small mammals and rodents, and the local communities are not particularly concerned about wildfires. As a result, most seedlings from natural regeneration do not survive the dry season, as shown by studies of the woodland structure in the Red Volta Valley (Adjewodah, Oduro, & Asase, 2012). Most of the plants (73%-82%) are less than 5 cm in diameter, thus the late dry season wildfires result in a high level of growth failure of these saplings and thereby prevent the succession of adult trees by the end of February every year. Wildfires also affect rivers, especially when they burn the moist gallery forests that have no fire-resistant adaptation compared to savannah woodland species.

Current evidence points to a dramatic shift in fire regimes worldwide. This is driven by a combination of land use change and climate change (Andela, et al., 2017) (Forkel, 2019) (Kelley, et al., 2019) (Bowman, et al., 2020). The risk of wildfires is affected by an increasing number of hot and windy days, as well as an accumulation of fuel load and an increased potential for fires being started either by people, or by natural events such as lightening. The future climate change scenarios for Tamale suggest that both the average daily temperatures and the number of hot days, will significantly increase, which is likely to contribute to an increasing risk of wildfires, and particularly with an increasing risk of ignition.

Climate change influences on fire can be categorised as: (1) direct effects on fire weather through drought, higher temperatures, and changes in the strength and seasonality of winds; (2) indirect effects resulting from changes in the nature and availability of biomass/fuel; and (3) direct and indirect changes in the frequency and location of natural- and human-caused ignitions via changes in dry lightning profiles, and changes in demographics and human behaviour resulting from revised climate and land management policies (Dale, et al., 2001) (Krawchuk, 2011) (McKenzie & Littell, 2017) (Restaino & Safford, 2018).

Climate change will directly affect the frequency and magnitude of extreme weather conducive to the outbreak and spread of wildfires. It will also lead to longer wildfire seasons where the fire season may begin earlier and end later. Increased wildfire activity can positively impact greenhouse gas emissions that reinforce climate change drivers (Figure 32).

Figure 32 I Potential reinforcing feedback loop of climate change on wildfires



Source: (UNEP, 2022)

7.5 Water Security

Neary half of the water used in Ghana originates from three international rivers (the Volta, Bia and Tano Rivers), that flow into the country from beyond Ghana's borders, placing the country at risk of **water insecurity** and political tensions, should water availability decline, either as a result of climate change or of increasing demands and changes in water management in upstream countries. Currently, tensions already exist between Ghana and Burkina Faso due to Burkina Faso's decision to withdraw its water from the Volta Basin, reducing water levels and impacting hydropower generation in Ghana[9].

The Volta Basin flows could be reduced by as much as 24% by mid-century, and by as much as 45% by end of the century, due to reduced rainfall and increased evaporation (USAID, 2017). Clean water and sanitation are a challenge for some areas and communities in Ghana, where approximately 25% of the population lacks access to clean water.

Declining rainfall, increased levels of drought and rising temperatures, in addition to increased pressures from a growing population, urbanization and industrialization, are likely to further compound the threat to water security. The reduced quantity and quality of water will be a significant challenge for human consumption, as well as for use in the agriculture, industry and hydropower sectors.

Poor areas in the country (especially the northern part) suffer disproportionally as a result of droughts, floods and soil erosion, which are having adverse affects on agricultural production. These areas are also impacted by challenges in flood management due to urbanization and flooding that is exacerbated by poor land use and limited mitigation infrastructure (Yeleliere, Cobbina, & Duwiejuah, 2018) (Obuobie, Kankam-Yeboah, Amisigo, Opoku-Ankomah, & Ofori, 2012). In Tamale, flooding events threaten alternative water supplies such as unprotected shallow wells and boreholes ((Kayaga, et al., 2021)). Flooding events in the area can also impact water resources that are recharged by rainfall due to the increasing potential for faecal contamination (Kayaga, et al., 2021).

Rainfall and evaporation changes also impact rates of surface water infiltration and recharge rates for groundwater, which, when coupled with low-water storage capacity and poor maintenance, increases the country's vulnerability to unreliable rainfall patterns. This has the potential for further decreased reliability of groundwater and surface water sources during droughts or prolonged dry seasons.

Climate change can also include secondary impacts such as extreme heat, which places particular pressure on women who travel increasingly greater distances to collect water (Kayaga, et al., 2021).

As part of the national level climate change risk assessment for infrastructure, the climate change risk for water supply to Tamale was considered to be very high as a result of an expected reduction in local surface water runoff. This result was based on the original CMIP5 climate scenarios, while the more recent CMIP6 climate models suggest a potential increase in precipitation. Increasing precipitation does not necessarily result in increasing water availability, as increasing temperatures will also lead to greater evaporation and losses, but it may be that the latest climate scenarios could result in less of an impact on surface water runoff. This is however likely to also be much more variable and, as a result, could still contribute to significant increasing water scarcity, particularly as a result of a lack of storage as well as increasing risks due to flooding and catchment degradation and sand mining.

In 2022 a study carried out by Anchor Environmental Consultants, South Africa, was commissioned by Catholic Relief Services (CRS), in partnership with The Nature Conservancy (TNC) to develop a business case for the investment in proposed nature-based solutions for the Tamale Water Fund[10], as well as to engage with key stakeholders to encourage their support for the prioritisation of investments. The results of this study indicate the benefits of improved catchment management and the control of sand mining, as being critical in reducing the impacts of climate change on water security and supply.

9 Republic of Ghana (2015). Ghana's Third National Communication to the UNFCCC. URL: https://unfccc.int/resource/docs/natc/ghanc3.pdf

10 CRS and partners begin processes to develop Water Fund for Tamale | Ghana News Agency (gna.org.gh)

7.6 Agriculture

Agriculture is a key sector for Ghana's economy, household livelihoods and food security. The sector employs more than half of the population on a formal and informal basis, and accounts for almost 20% of the GDP, as well as almost half of export earnings. This sector is the main source of livelihood for the majority of the country's poorest households. Two-thirds of non-oil manufacturing industries depend on agriculture for raw materials, and it accounts for a major share of all economic activities and livelihoods among smallholder farmers. Ghana produces a variety of crops in various climatic zones which range from dry savannah to wet forest, and which run in east-west bands across the country. Ghana's agricultural sector comprises crops, livestock, fisheries and forestry. The crops sub-sector includes industrial crops (e.g. cocoa, rubber, oil palm, coconut and cotton), starch and cereal staple crops (e.g. cassava, yam, maize, rice and plantain), and fruits and vegetables (e.g. pineapple, banana, cashew, citrus and mango). In Tamale, featured crops include maize, sorghum, yam and pulses (Gyasi, et al., 2014).

Rising temperatures and increased variability in rainfall, with a potential increase in the risk of droughts, are projected to lower the yields of major staple crops (cassava, yams, plantains, maize and rice).

Cassava yields, for example, are projected to fall by 29.6% by 2080, and maize yields by 7% by 2050. Cases of total crop failure are projected to occur approximately once every five years in Ghana's Northern Region due to delayed or diminished rainfall. Cocoa, a major cash crop and the country's second leading foreign exchange earner, is sensitive to rising temperatures as well as to drought. Suitable areas for cocoa production, mainly along the coast, are also decreasing due to temperature increase, floods, soil salinization and continued coastal erosion. Yield losses may additionally become more severe as interannual rainfall variability increases and the length of growing seasons shorten.

Research in Tamale suggests that farmers have already begun to experience impacts from changing rainfall patterns. For example, due to delayed summer rains, some farmers in the metropole have started planting cereal crops in July rather than in June (Gyasi, et al., 2014). Moreover, in Northern Ghana, the Kanshgu and Savelugu communities have begun to favour sorghum and cowpea species that are more resistant to drought and that have shorter growing seasons (Gyasi, et al., 2014).

Rising temperatures are likely to increase the presence of pests and diseases, potentially leading to crop failure and reduced yields, especially for cassava which is a key food staple. Reduced rainfall will shorten growing seasons, and the desertification of agricultural land brought about by unsustainable farming practices such as limited crop rotation and poor soil management, will further inhibit production (Pinto, Demirag, Haruna, Koo, & Asamoah, 2012).

Currently, in Tamale, piped water systems are unable to meet agricultural demands (Gyasi, et al., 2014). Groundwater sources can be helpful resources for farmers in Northern Ghana, although these sources are usually depleted during the dry season and require energy pump to the (Kadyampakeni, Morgan, Zekri, Ferrarezi, & Schumann, 2017). The use of solar photovoltaic pumps serve as an important tool in gaining access to groundwater resources in Northern Ghana, but widespread access to these tools is still limited (Gebregziabher, Birhane, Berihu, Belstie, & Teklay, 2020). Irrigation from wastewater sources can therefore play an important role in crop production, specifically in the Zagyuri and Sagani communities in Tamale (Abdallah & Mourad, 2021). It is estimated that approximately 60% of vegetable producers in the City rely on water from wastewater sources, including sewage tanks, septic tanks, dugouts and wells (Abdallah & Mourad, 2021). However, research suggests that utilizing these irrigation sources can have health implications for farmers and for those consuming subsequent produce (Abdallah & Mourad, 2021).

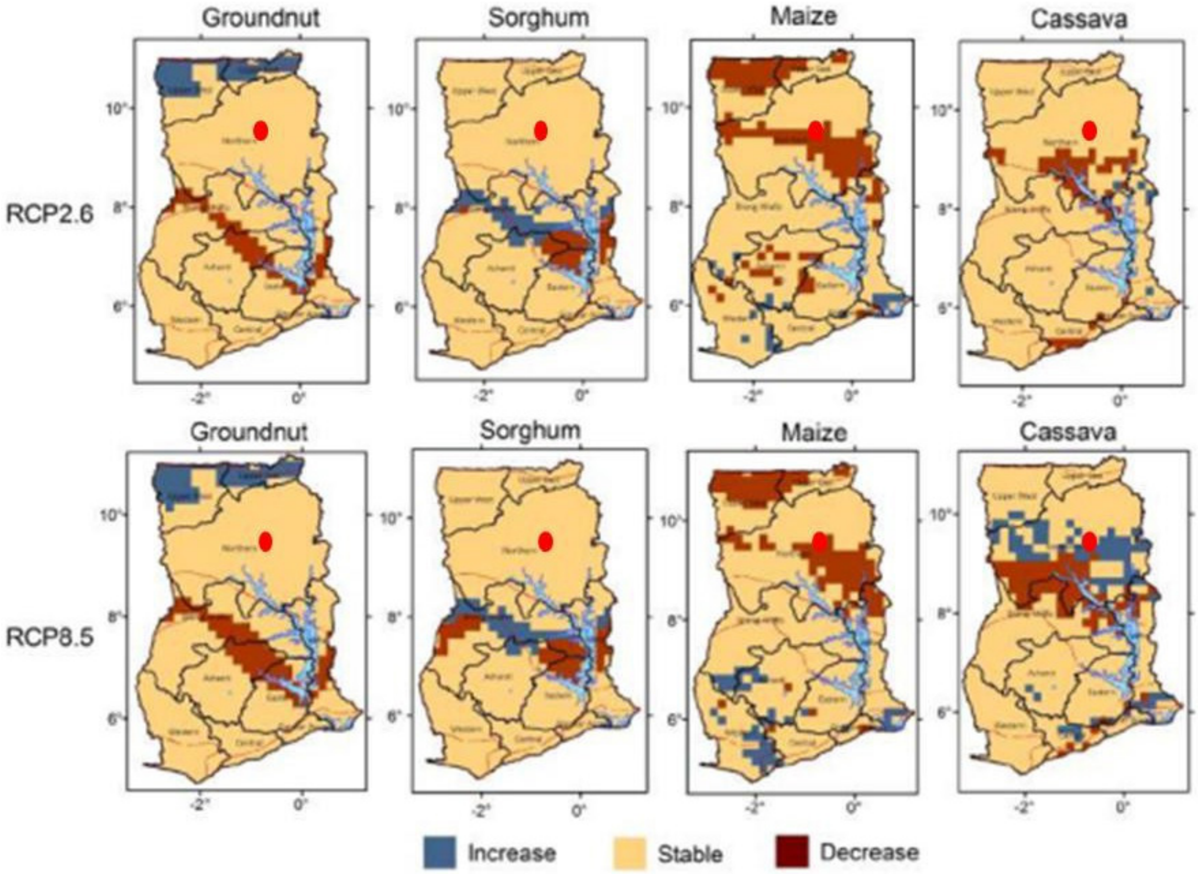
Tamale's urban and peri-urban agricultural systems also face threats from increased urbanization, which limits available farming land and increases food demand within the City (Gyasi, et al., 2014). Limited land availability has forced farmers to intensify farming techniques through increased fertilizer and pesticide use (Gyasi, et al., 2014). Climate stressors can therefore exacerbate existing challenges for farmers in the area by placing increased pressure on already diminishing land resources.

Animal production is an important part of agriculture in Ghana, as it plays a vital role in rural livelihoods of small-scale farmers for meeting needs such as food and income generation. Research focused on Northern Ghana found that more than 50% of surveyed farmers participated in mixed farming involving simultaneous crop production and livestock raising (Adzawla, Tahidu, Mustapha, & Azumah, 2019). In these farming systems, livestock can be used as work animals and for manure, both necessary in crop production. Cattle, pig, poultry, goat, and sheep are some of the predominant livestock species raised in Ghana. Cattle are mainly owned by men, and animal herding and trading is male dominated. Women tend to sheep and goats, clean enclosures and transport animal manure to the farms in support of their husbands. They also process and sell cow's milk and dairy products such as cottage cheese, which they sell to local consumers (DAI, & Nathan Associates London Ltd., 2014). Chickens are raised by women for household use.

Although the livestock production index in Ghana in 2019 indicated an increase from the preceding year, climate variability and change are a threat, especially through negative impacts on the major fodder sources, such as rangelands and crop residues. The adverse effects of climate change on livestock farming, and how to overcome such effects, is a situation that requires critical attention.

Crop and livestock productivity in Tamale is highly vulnerable to the effects of climate variability and change, because of its excessive reliance on rainfed agriculture, and due to extreme poverty. As a result, the sector is characterized by low productivity levels. Erratic precipitation patterns have severe consequences for productivity, as only 2% of the country's irrigation potential is in use. In addition to the direct impact of droughts, discussed in a previous section, climate change will likely have an impact on overall crop productivity. A recent study on the potential impacts of climate change on crop productivity across Ghana shows the impact that this will have, including impacts for Tamale (Figure 33).

Figure 33 | Modelled change in crop suitability for selected crops in Ghana under different scenarios



Source: (Murken, et al., 2019)

Based on the results from this study, it is likely that maize will be the most severely impacted crop type in the region of Tamale, with an expected decrease in crop productivity under both RCP2.6 and RCP8.5. This analysis suggests a potential for increased productivity for Cassava under RCP8.5. The most recent climate models (CMIP6) suggest a possible increase in rainfall for Tamale and the Northern Region of Ghana, which could potentially improve crop productivity for some crop types in the area. This is however likely to be accompanied by increased variability in rainfall and a greater risk of flooding.

Overall, climate impacts on this sector can also have important implications for vulnerable groups, including women and children. Research focused on Northern Ghana found that male farmers had a higher climate adaptation capacity relative to women (Adzawla, Tahidu, Mustapha, & Azumah, 2019). Thus, female farmers tended to experience more intense climate change related impacts than men (Adzawla, Tahidu, Mustapha, & Azumah, 2019).

Disruptions to crop yields due to climate change could potentially limit the roles of ‘market queens’, or women who buy and sell produce in the metropolis (Nchanji & Nchanji, 2022). Additionally, potential declines in crop yields can impact food security and affect infants and small children by promoting malnutrition. A cross-sectional study of 240 women and child pairs in South Tamale, indicated that around 8% of children suffered from wasting and 29% suffered from stunting (Bakuri Suara, Ziblim, Abukari, Ntim Sarpong, & Sulemani, 2022).

Table 16 l Expected Change in Crop Suitability by 2050 (Tamale) (from Figure 33)

Crop Type	RCP2.6		RCP8.5
Groundnut	Stable		Stable
Sorghum	Stable		Stable
Maize	Decrease		Decrease
Cassava	Stable		Increase

7.7 Health

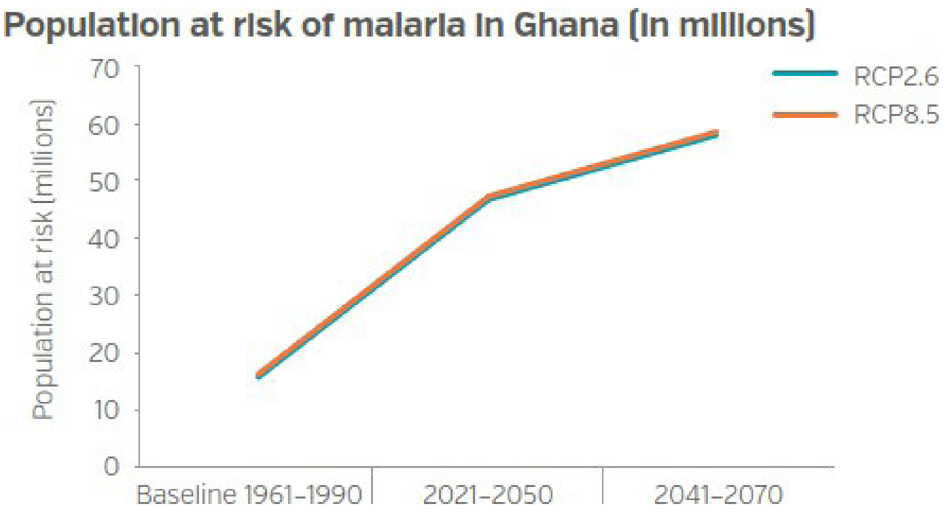
Ghana is highly vulnerable to the negative health implications of climate change. Changes in key climate hazards are expected to impact food and water security, human settlements, infrastructure and ecosystems, and increase the prevalence and geographic extent of vector and waterborne diseases. Increased disease prevalence will be immensely significant in densely populated urban areas, such as Tamale, where temporary settlements lack access to clean water and sanitation.

The impacts of climate change on health further exacerbate existing health disparities, and disproportionately affect vulnerable communities such as low-income and marginalized populations by compounding the existing burden of disease and the barriers to health services access, often at the times when they are most needed. Flash floods, which have recently become more common in Tamale, commonly lead to cholera outbreaks across the country. Malaria remains a significant challenge and is likely to increase as temperatures rise and flooding becomes more common, particularly in coastal and urban areas (USAID, 2017). Flooding also damages critical health infrastructure like hospitals. Access to improved sanitation is low in Ghana (20% of urban and 9% of rural populations). In Tamale, the local government, with support from UNICEF, has implemented an Urban Sanitation Project, with the aim of decreasing open defecation and increasing the availability of latrines. In 2021, the project exceeded initial goals by having over 17,000 household toilets in use, decreasing open defecation by 35% compared to 2015 values (GNA, 2021). This will help in reducing the potential impacts of climate change and the resulting impact on water quality and human health.

As climate change places increased pressure on water sources, this can have important health implications given the use of wastewater for agricultural production. Sampling of wastewater irrigation sources in Tamale showed *E. coli* concentrations that exceeded WHO standards, and heavy metal contaminants that exceeded thresholds by the Food and Agriculture Organization (FAO). Researchers concluded these contaminants can make subsequent agricultural products dangerous to consume (Abdallah & Mourad, 2021).

Climate and socioeconomic factors affect the spread of some vector and waterborne diseases. Temperature, precipitation and humidity strongly influence the lifecycles of the vectors and the infectious agents that carry and control the transmission of waterborne and vector-borne diseases. With the changing climate, changes in precipitation patterns are eminent, and temperatures are expected to rise in Tamale. Warmer temperatures will increase the range and reproduction rates of disease-carrying parasites such as mosquitos and ticks, and thus increase the incidence of diseases like malaria and dengue fever. At the same time, changes in precipitation patterns can cause stagnant water to form, serving as a breeding ground for disease-carrying organisms. Population growth will also increase the population at risk, in areas where malaria presence is static in the future. According to the study by the World Health Organisation (WHO), under high (RCP8.5) and low (RCP2.6) emissions scenarios, over 58 million people are projected to be at risk of malaria in Ghana, by 2070 (WHO, 2015). However, the fact that there appears to be very little difference between the impacts of RCP2.6 and RCP8.5, suggests that climate change itself has only a limited impact on the number of people at risk, as compared to other factors such as population growth or the number of people living in areas increasingly impacted by malaria.

Figure 34 I Population at risk of malaria in Ghana

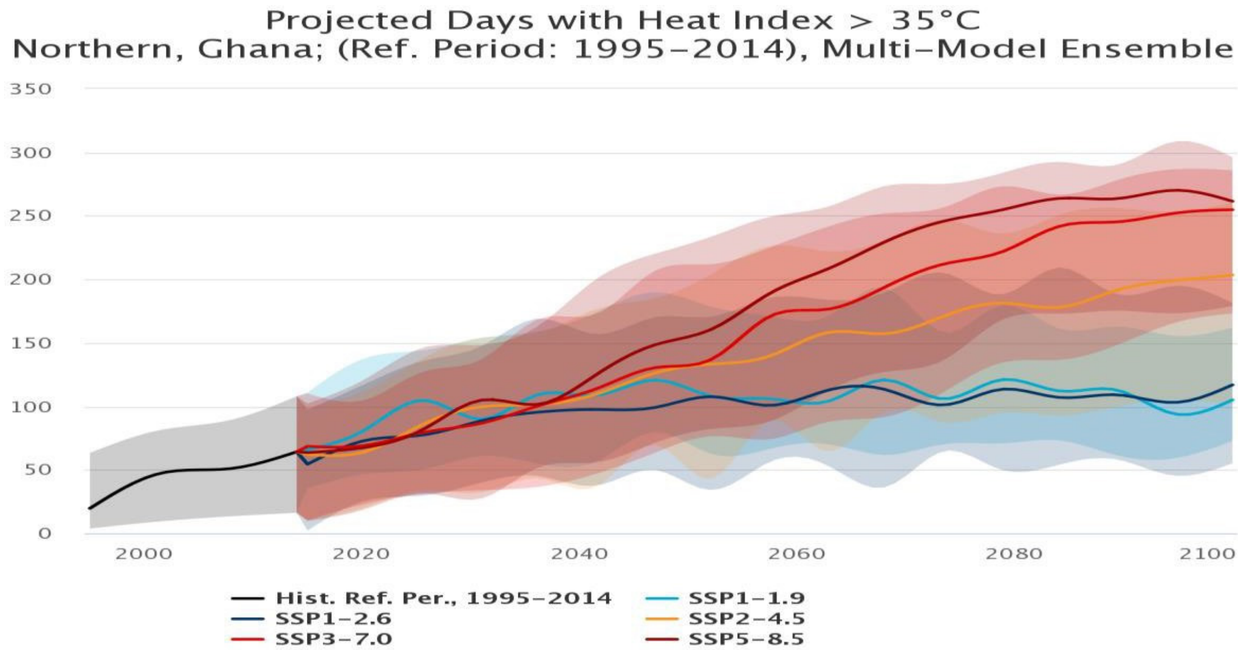


Source: (WHO, 2015)

The health of Tamale's population is expected to be aggravated by heat stress, other vector-borne diseases such as dengue fever and yellow fever, air pollution, communicable diseases such as HIV/AIDS, cholera and TB, and other respiratory diseases. Higher temperatures, land and water scarcity, flooding, drought, and displacement, will all impact agricultural productivity and can contribute to breakdowns in food systems. This disproportionally affects those most vulnerable to hunger and can lead to food insecurity. Vulnerable groups risk further deterioration into a food and nutrition crisis, if exposed to extreme weather events. Without considerable efforts made to improve climate resilience, the risk of hunger and malnutrition could increase globally by up to 20% by 2050.

In Ghana, the prevalence of child malnutrition in children under age five is 13.4% (WHO, 2015). Under a high emissions scenario, heat-related deaths in the elderly (65+ years) are projected to increase to 70 deaths per 100,000 by 2080, compared to the estimated baseline of approximately 2 deaths per 100,000 annually between 1961 and 1990 (WHO, 2015). The annual distribution of days with a high-heat index provides insight into the health hazard of heat. The expected increase in the number of high heat index days (>35° C) for the Northern Region in Ghana under different climate scenarios, is shown in Figure 35.

Figure 35 I Expected increase in days with a High Heat Index for the Northern Region in Ghana



8 Climate Change Risk Assessment

8.1 Climate Risk Narratives

The impact storylines, or climate risk narratives, are descriptions of the future climate, environment, economic activities and society under a changed climate for a given location or region, and a specific climate scenario. The purpose of developing impact storylines is to identify the specific climate-related risks, and the causal links to priority sectors that should be evaluated. Such narratives constitute an integrative communications device that shows promise of being more effective than presenting technical maps of climate statistics, and better suited to integrating into broader scenario development and planning processes. As a communication tool, the climate scenario analysis forms the basis for developing the impact storylines, describing a range of future climate scenarios including various interactions between climate variables (e.g. temperature, wind, evapotranspiration etc) and potential impacts.

The impact storylines should be based on analogues of major climate events or disasters that have happened in the past in the area or nationally and, based on that, an analysis of what main factors gave rise to the vulnerability. This will give a credible basis to the projected impacts in the storylines. The main indicators should then be modelled into the future, given trends and projections. Adaptation solutions will soon become obvious in the course of this exercise.

The purpose of the climate risk narratives is to identify the specific climate-related risks, and the causal links, that should be evaluated, and to present these in a simplified form. These impact storylines also help to confirm which are the relevant first- and second-order risk domains that require further investigations. These narratives are intended as discussion starters for engagement with stakeholders in order to ground truth the narratives in line with the local context towards realistic adaptation responses. They also provide a basis to analyse possible different futures, and to plan for adaptation, considering the uncertainty of future climate.

The two climate risk narratives were developed for TaMA representing a 2053 future state, based on an initial assessment of the underlying social and economic conditions, the critical economic sectors, and the anticipated climate-related hazards, after stakeholder engagements were undertaken.

It is important to note that the two narratives selected do not represent every scenario projected by the climate models, but are rather considered representative of a possible range of future climate scenarios.

Figure 36 | Increasing water security and drought risks for TaMA

TaMA Climate in 2053: Warmer and Drier

Welcome to the Tamale Metropolitan Assembly in Ghana. The year is 2053 and the changing climate has presented a myriad of challenges for the people of Tamale. With 10% less rain, and average temperatures 2ºC warmer than in the past, droughts and sizzling heat waves are now part of the region's rhythm.

In this ever-warming and dry city, health troubles such as heatstroke and dehydration affect everyone, especially the elderly, outdoor workers and children. Wealthier populations have opted for air conditioning, which only pushes electricity demand up, adding more pressure on Tamale's already stretched energy network. Local water sources have run dry and crop yields are significantly less.

Decades ago, Tamale had a thriving farming industry. Sadly, those days are fading. For the past 30 years the dry spells have become longer and more frequent during the growing season, alternating with unpredicted intense rainfall events, and food security has become a pressing issue due to declining crop yields and scarce water resources. The City's population has been growing by 3.5% annually, adding to the water security risk. As water shortages grip the area, people find it increasingly difficult to access clean drinking water. Traditionally, women and girls bear the responsibility of water collection and household chores. This burden now weighs heavier than ever as they travel great distances to secure water for their families. Unfortunately, their health suffers, and education and income generation opportunities are slipping away.

Due to the impacts of catchment degradation, evapotranspiration, pollution and sand mining, water resources in Tamale are diminishing, making it challenging to access clean water. Additionally, rain is no longer sufficient to recharge aquifers for groundwater extraction. Nevertheless, Tamale remains committed to protecting its community and way of life by implementing climate and gender-sensitive plans to make businesses and communities less vulnerable to climate risks and to help citizens adapt.

A particular focus for Tamale is on protecting critical water sources. This includes both the protection of the local catchment area, as well as addressing major concerns of sand mining and catchment degradation in the White Volta Basin, which is the major water supply source for the City. Furthermore, efforts to minimise the impact of increasing temperatures on heat stress in the City requires not only the design of more energy efficient houses, that are better insulated against the heat, but also efforts to protect and rehabilitate green spaces within the City, particularly trees that are indigenous to the area.

Tamale stands at a turning point, with people from all walks of life joining hands to tackle the challenges of climate change. With determination and an unwavering spirit, the people of Tamale are paving the way for a sustainable, inclusive and resilient future, including investing in nature.

(Photo credit: Tony Akpene Klu1) *(Photo credit: savannanews.blogspot.com)*

https://www.modernghana.com/news/1180318/the-role-of-wacwisa-uds-in-sustainable-agriculture.html

Figure 37 l Climate Risk Narrative for TaMA: Narrative 1 – Warmer and Drier

Climate Risk Narrative 1

Tamale Metropolitan Assembly

Warmer & Drier

Climate Zone: **North**

by 2053

RCP 4.5 | 40% likelihood

Average annual temperature will **increase**: +4% (~1.5°C)

There is chance of **decrease** in mean annual precipitation: -8%

There is a slight chance for **increase** in dry spells and in number of hot days: +2% (~1 day)

There is a chance for **increase** in extreme rainfall events: +25%

Potential Impacts

Energy Security

Failure to meet energy demand during heatwaves and hot days for the growing population due to reduced hydropower potential.

Water security

Failure to meet water demands for growing population, agriculture and other water intensive industries due to increasing variability in precipitation and drought and failure of Integrated Water Resources Management.

Agriculture-Crops

Decline in agriculture production and increase in food insecurity due to drought, change in precipitation patterns and water availability.

Health

Increase in heat stress and stroke related diseases, vector- and water-borne diseases, respiratory problems and psychological challenges due to the displacement of communities.

Forestry

Increase in loss of forest resources due to drying and increased fire risk.

Livelihoods

Loss of livelihoods which includes: crop failures, loss of grazing land, and reduced access to fresh water, all leading to food insecurity and economic hardship for communities.

Migration

High rates of migration due to drought, water scarcity and changes in livelihoods, particularly in rural areas.

Infrastructure

Economic and social disruptions due to critical infrastructural failure because of flooding and increased number of hot days.

No- or Low-Regret Adaptation Measures

Energy Sector

1) Resilient and green energy access in drought-prone districts.

2) Capacity development and regulatory frameworks to support local renewable energy generation, including solar energy, to enhance resilience of remote, vulnerable communities.

3) Update energy sector design standards to incorporate climate risks and adaptation measures.

Water Sector

1) Water supply resilience through increased storage capacity and regional collaboration on Integrated Water Resources Management.

2) Improved access to secure water sources and water supply system.

3) Improved Integrated Water Resources Management and regional collaboration.

4) Climate adaptation alignment across water sector institutions and planning mechanisms to ensure integrated water resources management including with upstream countries.

5) Proactive risk-informed asset management of infrastructure.

6) Reduce sand mining and catchment degradation.

Agriculture Sector

1) Promote climate-resilient crops and agricultural practices.

2) Enhance capacity building and training in climate-resilient agriculture practices.

3) Improve access to climate information and knowledge on climate change impacts.

4) Develop insurance schemes and risk mitigation tools for agriculture.

5) Diversification of crop types and drought resistant varieties.

6) Investment in irrigation systems and water storage facilities.

Health Sector

1) Strengthen health infrastructure and emergency preparedness.

2) Develop and implement early warning systems for disease outbreaks.

3) Enhance community health and engagement.

4) Promote environmental health and sustainability.

5) Integrate climate change into health policies and programs.

6) Adopt nature-based solutions to help with 'cooling' of the city.

Figure 38 | Aerial view of the affected infrastructure in Tamale during past flood events

TaMA Climate in 2053: Hotter and Wetter

The year is 2053, and the vibrant city of Tamale, Ghana's fourth largest metropole, faces a challenging future. Climate change has redefined the region, with sweltering heat and torrential rains becoming the new norm. In this era, temperatures have soared by an astonishing 2ºC, and annual precipitation has surged by 10%. Gone are the days when a once-in-a-century rainfall was a rarity. Now, such events are 3.6 times more likely to occur, escalating the risk of catastrophic floods.

The citizens of Tamale confront a new reality, as the harsh conditions not only threaten their homes but also contribute to the spread of deadly diseases. The climate change trifecta of rising temperatures, increased precipitation and elevated humidity, has created the perfect storm for vector and waterborne illnesses. Mosquitos and ticks, that thrive in these conditions, carry diseases like malaria and dengue fever, while stagnant water becomes a breeding ground for infectious agents.

Toxic algal blooms have also become a common occurrence, further endangering public health. This is as a result, not only of the hotter and wetter conditions, but also of the failure to manage pollution, and in particular due to poor sanitation. Amidst this turmoil, women, who have long faced marginalization in Tamale, bear the brunt of the consequences, their vulnerability intensified by the City's climate risks.

The situation is further complicated by Tamale's reliance on climate-sensitive industries, such as agriculture and trading, for its economic livelihood. High poverty levels leave communities with limited resources to adapt to these new and ever-changing conditions, making it crucial for the City to develop gender-sensitive strategies that prioritize women and other vulnerable groups.

Faced with crumbling infrastructure and eroding landscapes, increasing flood risks, and soaring health costs, the people of Tamale continue to persevere, striving to build a future that is both resilient and inclusive. They recognize that, while the challenges are great, there is still hope and opportunity for change as they work together to navigate the uncertain waters of climate change.

Addressing the increasing flood risks is a priority, requiring significant investments in improved urban drainage systems and early flood warning systems. It has also been recognised how important it is to invest in nature-based solutions, as these help by absorbing some of the flood peaks and to cool the City. The hotter and wetter climate makes it even more important to invest in sustainable sanitation and improved public health systems, including better protection of and access to critical health facilities.

(Photo credit: Geoffrey-Buta[1]) *(Photo credit: Abdul Karim Naatogmah/citifmonline.com/Ghana[2])*

https://www.modernghana.com/news/1180318/the-role-of-wacwisa-uds-in-sustainable-agriculture.html

1– Source: https://www.ghanaiantimes.com.gh/tamale-hit-by-floods-after-torrential-rain-renders-many-homeless-more-than-100-homes-properties-submerge/

2- https://citifmonline.com/2014/09/heavy-rains-submerge-parts-

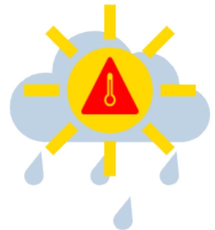
Figure 39 I Climate Risk Narrative for TaMA: Narrative 2 – Hotter and Wetter

Climate Risk Narrative 2

Tamale Metropolitan Assembly

Hotter & Wetter

Climate Zone: **North**



by 2053

RCP 8.5 | 25% likelihood

Average annual temperature will **increase**: +8% (~2.1°C)

There is chance of **increase** in mean annual precipitation: +22%

There is a chance of **increase** in number of hot days: +10% (~3 days)

There is chance of **increase** in extreme rainfall events: +120%

Potential Impacts

Energy Security

Failure to meet energy demand during heatwave and hot days for the growing population and reduced efficiency of thermal power.

Water security

Failure to meet water demands for growing population, agriculture and other water intensive industries due to increasing rainfall variability, sedimentation and damage to infrastructure due to flooding as well as failure of Integrated Water Resources Management.

Agriculture-Crops

Excessive rainfall and flooding could damage crops and reduce yields, particularly if the intensive rain occurs during sensitive stages of plant growth. The wetter climate conditions could also increase the prevalence of pests and diseases, which could harm the crops.

Health

Increase in vector- and water-borne diseases due to flooding and psychological challenges due to the displacement of communities.

Forestry

Increase in loss of forest resources, since wetter climate conditions could increase the prevalence of pests and diseases, which could harm trees.

Livelihoods

Loss of livelihoods leading to food insecurity and economic hardship for communities.

Migration

Increased precipitation, flooding and landslides could force people to migrate to safer areas.

Infrastructure

Economic and social disruptions due to critical infrastructural failure because of flooding and increased number of hot days.

No- or Low-Regret Adaptation Measures

Energy Sector

1) Resilient and green energy access.

2) Capacity development and regulatory frameworks to support local renewable energy generation, including solar energy, to enhance resilience of remote, vulnerable communities.

3) Update energy sector design standards to incorporate climate risks and adaptation measures.

Water Sector

1) Water supply resilience, and flood risk reduction, through investing in improved catchment management and nature-based solutions.

2) Enhancing service delivery, focusing on human rights alongside the responsibilities and obligations.

3) Improved and more equitably Integrated Water Resources Management.

4) Climate adaptation alignment across water sector institutions and planning mechanisms to ensure integrated water resources management at local level and with upstream countries.

5) Proactive risk-informed asset management of infrastructure.

6) Reduce sand mining and catchment degradation.

7) Protect water infrastructure facilities against floods.

Agriculture Sector

1) Promote climate-resilient crops and agricultural practices.

2) Enhance capacity building and training in climate-resilient agriculture practices.

3) Improve access to climate information and knowledge on climate change impacts.

4) Develop insurance schemes and risk mitigation tools for agriculture.

5) Enhance the governance of climate-sensitive resources.

6) Diversification of crop types and resistant to pests.

7) Investment in irrigation systems and storage facilities.

Health Sector

1) Strengthen health infrastructure and emergency preparedness.

2) Develop and implement early warning systems for disease outbreaks.

3) Enhance community health and engagement.

4) Promote environmental health and sustainability.

5) Integrate climate change into health policies and programs.

6) Adopt nature-based solutions to help with 'cooling' of the city.

8.2 Systems and Assets Exposed to Climate Hazards

The climate analysis and baseline research (presented in the previous sections) revealed that Tamale is already affected by several climate extremes, such as unpredictable and erratic rainfall (floods and droughts) and temperature extremes, and that these are likely to increase into the future.

During the engagement process in the stakeholder workshop, the climate hazards common to Tamale were validated, to determine climate hazards through the stakeholders' perceptions.

While identified climate hazards reflect important threats to stakeholders, they may not capture the full extent of climate hazards in the area, such as impact on water resources in the White Volta Basin. Table 17 presents the top climate hazards identified by the stakeholders that pose climate-related risks to the livelihoods and lives of the communities under the current conditions of Tamale.

Table 17 I Climate change hazards identified during the Tamale stakeholder workshop (29-Nov-2022)

Systems and Assets Exposed to Climate Hazard	Climate Hazard	Climate risk and potential impacts
Damage to water treatment plant	Extreme Rainfall	Heavy precipitation can lead to damage of the water treatment plant.
	Prolonged Drought	Droughts and changing precipitation patterns can affect the availability, and the quality, of the water for communities and businesses who use both local sources and regional sources.
	Floods	Heavy precipitation can lead to flooding and damage of the water treatment plant. This is added to by releases from the upstream Bagre Dam when the dam exceeds its maximum level. Floodwaters also carry large amounts of sediment that affects the water quality and operation of the treatment plant. Increased sediment loads also raise the bed level and increase flood risk. Catchment degradation and sand mining further increases sediment.
Water Supply Systems and Infrastructure	Extreme Rainfall, Flooding and Storms	Extreme weather events, such as storms and floods, can cause damage to water supply infrastructure and disrupt operations.
	Drought	Droughts and changing precipitation patterns can affect the availability, and the quality, of the water for communities and businesses who use both local sources and regional water sources.
Water Resources	Higher Temperatures and Evaporation	Rising temperatures can lead to increased evaporation and lower surface and groundwater levels of both local and regional sources.
	Extreme Rainfall	Heavy rainfall events can lead to surface water runoff and erosion.
	Drought	Prolonged dry periods can lead to lower river and stream flows.
	Flooding	Flooding causes erosion and increased sediment loads in rivers leading to the contamination of water resources.
Communities along Riverbanks	Flooding	Fluvial flooding can damage homes and other forms of property around the riverbanks, leading to financial losses for communities and disrupting people's livelihoods, and damage to crop lands.

Systems and Assets Exposed to Climate Hazard	Climate Hazard	Climate risk and potential impacts
Urban Flooding and Stormwater Management	Frequent and Intense Storms	Changes in precipitation patterns can lead to more frequent and intense storms, that can overwhelm the capacity of stormwater systems and increase the risk of urban flooding.
Damage to Road Infrastructure	Flooding	Heavy precipitation and increased frequency of floods can cause washouts, landslides and erosion of rural roads, making them impassable and difficult to access.
	Storms	Storms can damage or destroy roads, bridges and other infrastructure, causing disruptions to transportation and hamper access to essential services.
	High Temperatures	High temperatures can cause roads to expand and contract, leading to cracking, potholes and other types of damage.
Agriculture	Rising Temperatures and more Variable Precipitation.	Rising temperatures, more extreme weather events, and changing precipitation patterns all have adverse effects on crop yields and livestock health. Crops fail due to floods, waterlogging, drought, extreme heat and storms. A potential change in crop suitability is also expected.
	Changing Precipitation Patterns (more frequent dry spells and floods)	Heavy precipitation and increased frequency of floods can cause waterlogging and damage to crops, while dry spells and prolonged drought lead to water shortages and crop failure.
	Storms	Increased number of storms can lead to crop failure.
	Pests	Increasing temperatures and precipitation (i.e., more flooding) are likely to increase the risk of infestation of pests and diseases, leading to crop failure and reduced livestock production.
	Hotter Temperatures	Hotter temperatures will reduce livestock productivity.
Health Systems	Bushfires	Hotter temperatures can lead to more bushfires, which will contribute to poorer air quality and increased exposure to pollutants, which can exacerbate respiratory and cardiovascular illnesses.
	Changes in Temperature and Precipitation	Changes in temperature and precipitation can alter the distribution and abundance of malaria-carrying mosquitos, leading to a potential for an increased risk of malaria.
	Flooding and Heavy Precipitation	Flooding and heavy precipitation can increase the risk of waterborne diseases such as cholera, typhoid and diarrhoea. Flooding can also damage critical health infrastructure and limit access to hospitals.
	Climate Extremes	Floods, storms and wildfires can lead to displacement, loss of property and trauma, which can contribute to mental health issues such as anxiety and depression, as well as to direct physical impacts.

8.3 Impact Chain Analysis for Critical Systems and Assets

In order to better understand the climate change related hazards, and the vulnerability and exposure for the critical assets identified by the stakeholders, individual impact change ??? were developed. These were based on information provided by the stakeholders, for the following identified priority risks:

- Risk 1: Lack of clean and safe water for the community, for livelihoods and for business.
- Risk 2: Flooding of critical infrastructure, crop lands, buildings and settlements.
- Risk 3: Increase in occurrence and spread of diseases.
- Risk 4: Decline in agricultural production and food insecurity.
- Risk 5: Loss of livelihoods.

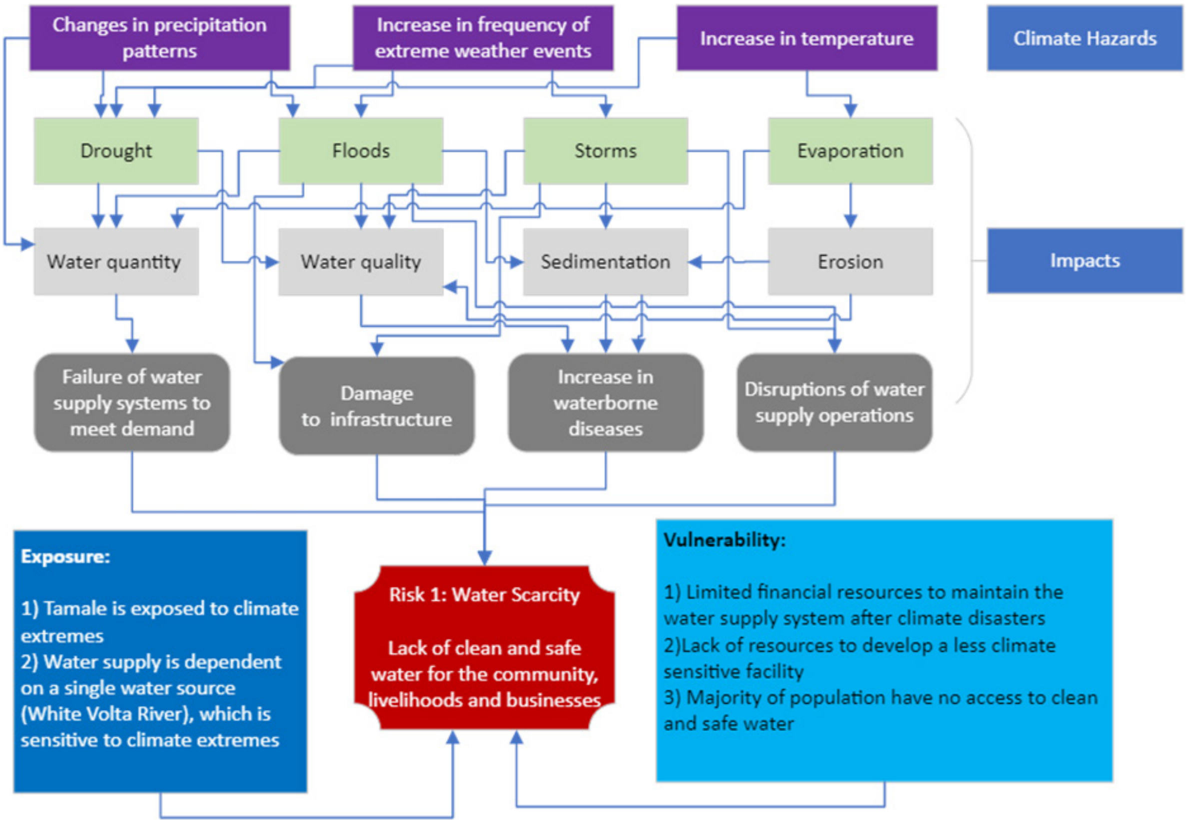
8.3.1 Risk 1: Water Security

Climate change is expected to exacerbate water scarcity challenges, and the impacts will likely disproportionately affect women and girls. Rising temperatures and changing precipitation patterns can lead to droughts and altered river flows, which can decrease the availability of fresh water for human and ecosystem needs. In many communities, women and girls are often responsible for collecting and managing water resources. The increased scarcity and decreased water availability may increase their workload and limit their opportunities for education and for income-generating activities.

In Tamale, there is a risk of significantly higher temperatures under all emission scenarios, even at lower GHG concentration scenarios. Precipitation projections are statistically insignificant under lower emission scenarios. However, under RCP8.5, precipitation will significantly increase. The temperature increases and the possible change in precipitation patterns will bring unprecedented impacts on water resources and worsen water scarcity. These, coupled with increased urbanization and unmet water supply demands from piped sources, can exacerbate issues of water quality and security.

Climate change can also increase the frequency and severity of extreme weather events, such as floods and storms, damaging the water treatment plant and water supply infrastructure and contaminating water supplies. Increased flooding also leads to increased costs for the treatment of water for consumption purposes.

Figure 40 I Water Security Risk Impact Chain Diagram

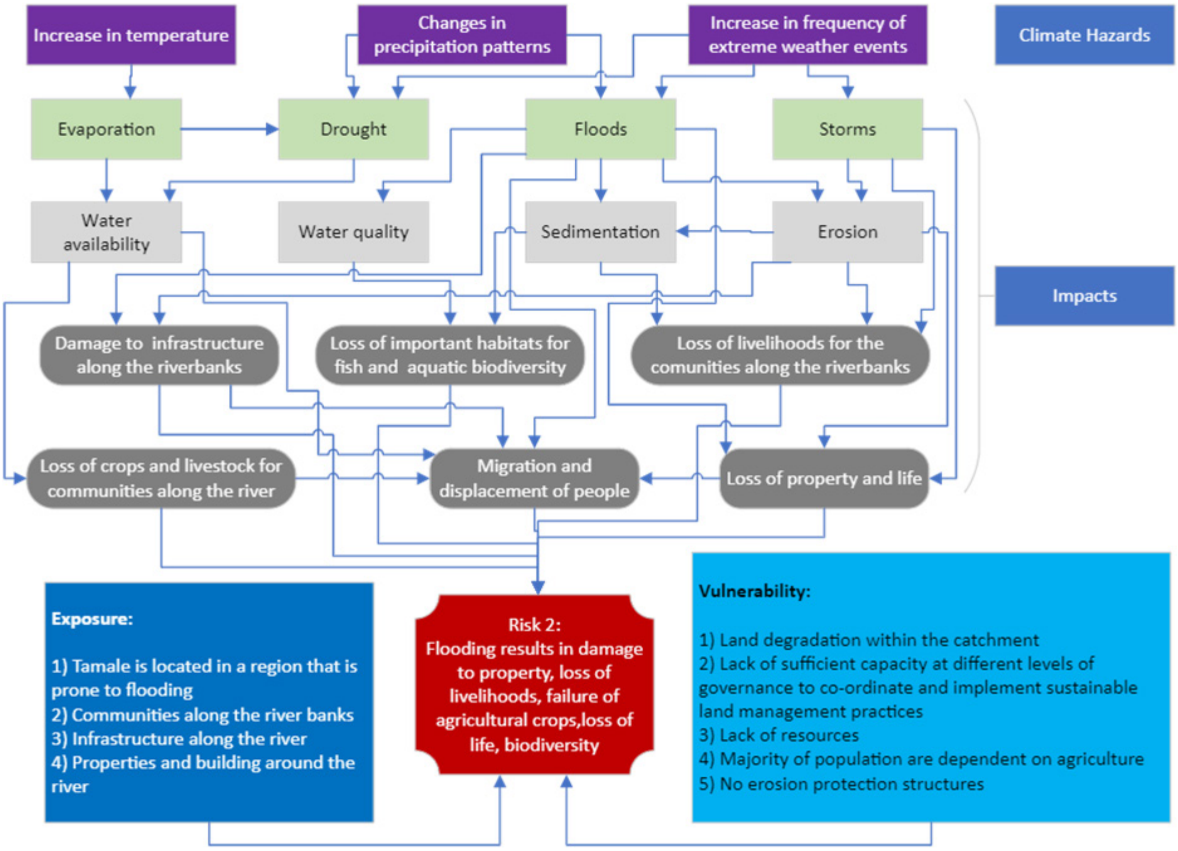


8.3.2 Risk 2: Flooding

Flooding has become an annual phenomenon in Tamale Metropolis, affecting livelihoods and causing significant property damage and loss of lives. A combination of factors, including heavy rainfall, deforestation, and changes in land use, increase the risk of flooding. The impacts of fluvial flooding can be severe for communities and for the natural environment. Flooding can cause damage to homes along the riverbanks and infrastructure, and disrupt transportation and communication systems. For the environment, river flooding can cause erosion, sedimentation, destroy habitats and displace wildlife.

Floods also have long-term impacts on the soil and water quality, affecting agriculture and livestock.

Figure 41 I Flooding Impact Chain Diagram

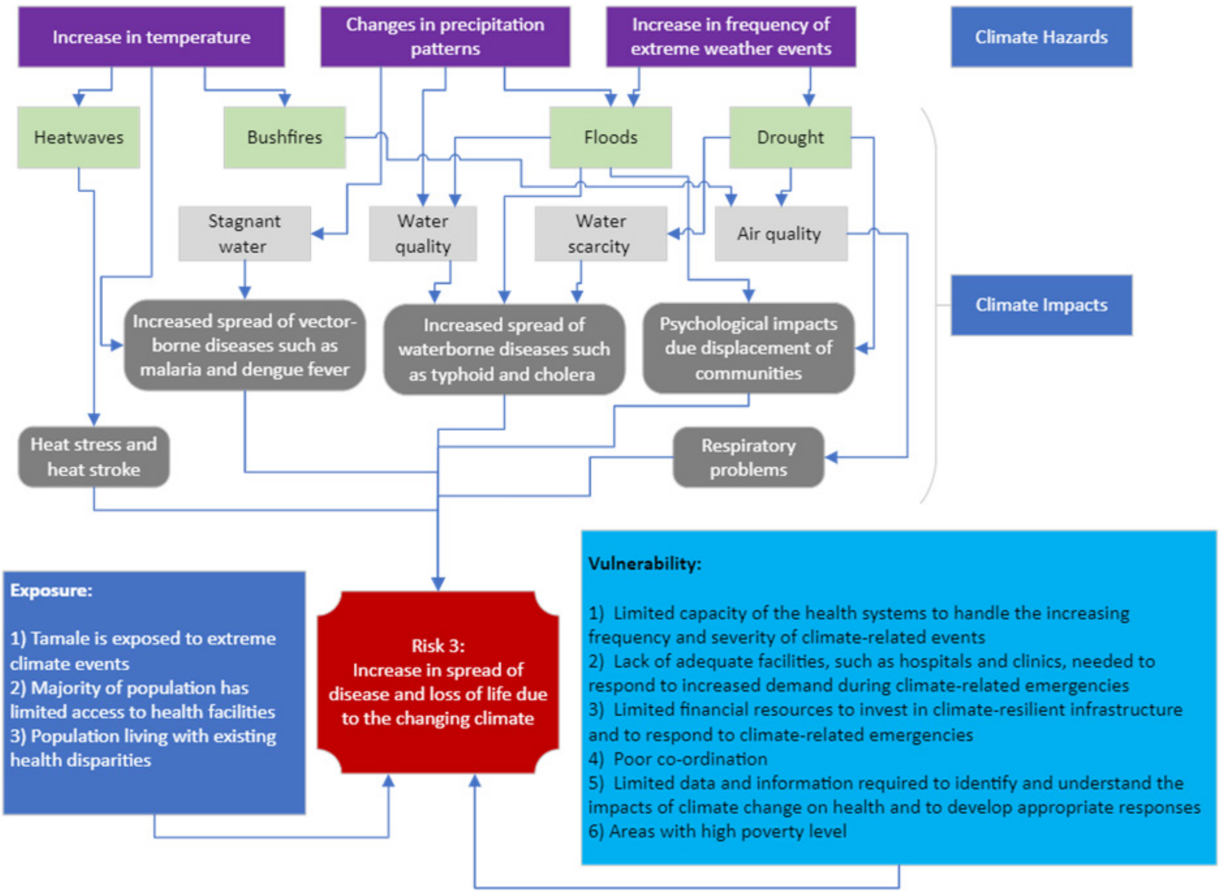


8.3.3 Risk 3: Community Health

Climate change impacts are far-reaching and detrimental to human health, affecting both mental and physical health. Tamale is particularly vulnerable to climate hazards such as heatwaves, bushfires, floods and drought, affecting the community health through some of the following climate impacts: increased heat stress and stroke, increase in vector and waterborne diseases, increased respiratory problems and psychological challenges due to the displacement of communities. The spread of climate-related diseases, injuries and loss of life are becoming common due to climate hazards.

The conditions are exacerbated by underlying vulnerabilities such as gender inequality, high poverty levels, limited access to health facilities, and a population with already existing health disparities. Pregnant women, small children, and senior citizens are especially at risk from water-related diseases such as cholera, typhoid and malaria.

Figure 42 I Health System Impact Chain Diagram

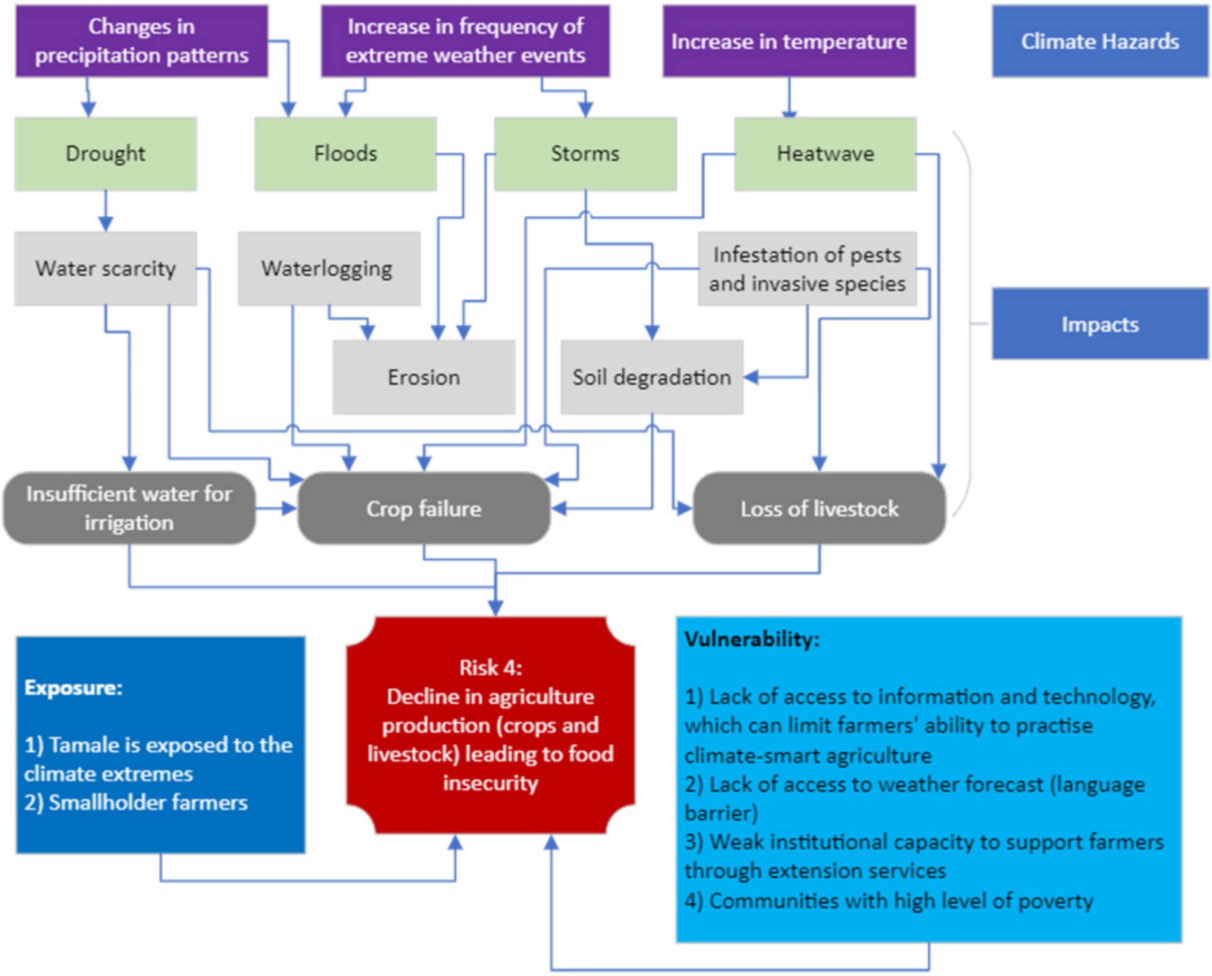


8.3.4 Risk 4: Agricultural production

The changes in climate have detrimental impacts on agricultural production due to an increase in drought, floods, heatwaves and storms. Such hazards directly increase exposure of smallholder farmers to climate impacts due to reduced rainfall and water availability for irrigation, resulting in an increased risk of crop failure and loss of livestock which, in turn, increases poverty levels. The impacts are worsened by factors such as a lack of access to information and technology (climate-smart agriculture), lack of access to weather forecasts, lack of water storage, and weak institutional capacity to support the farmers, as well as catchment degradation. These impacts are likely to disproportionately impact female farmers who generally have less access to agricultural inputs (Bryan & Garner, 2017).

Overall, a decline in agricultural production can increase the risk of food insecurity and a decrease in nutritional quality, potentially increasing vulnerability to diseases and impacting overall labour productivity and health.

Figure 43 I Agriculture Impact Chain Diagram



8.3.5 Risk 5: Loss of Livelihoods

Livelihoods are affected by climate hazards such as flooding, heavy rainfall, drought, increased temperature and evaporation. These will likely have the greatest impact on small-scale farmers and fishers, the unemployed, poverty-stricken communities, and those living within the flood-prone areas.

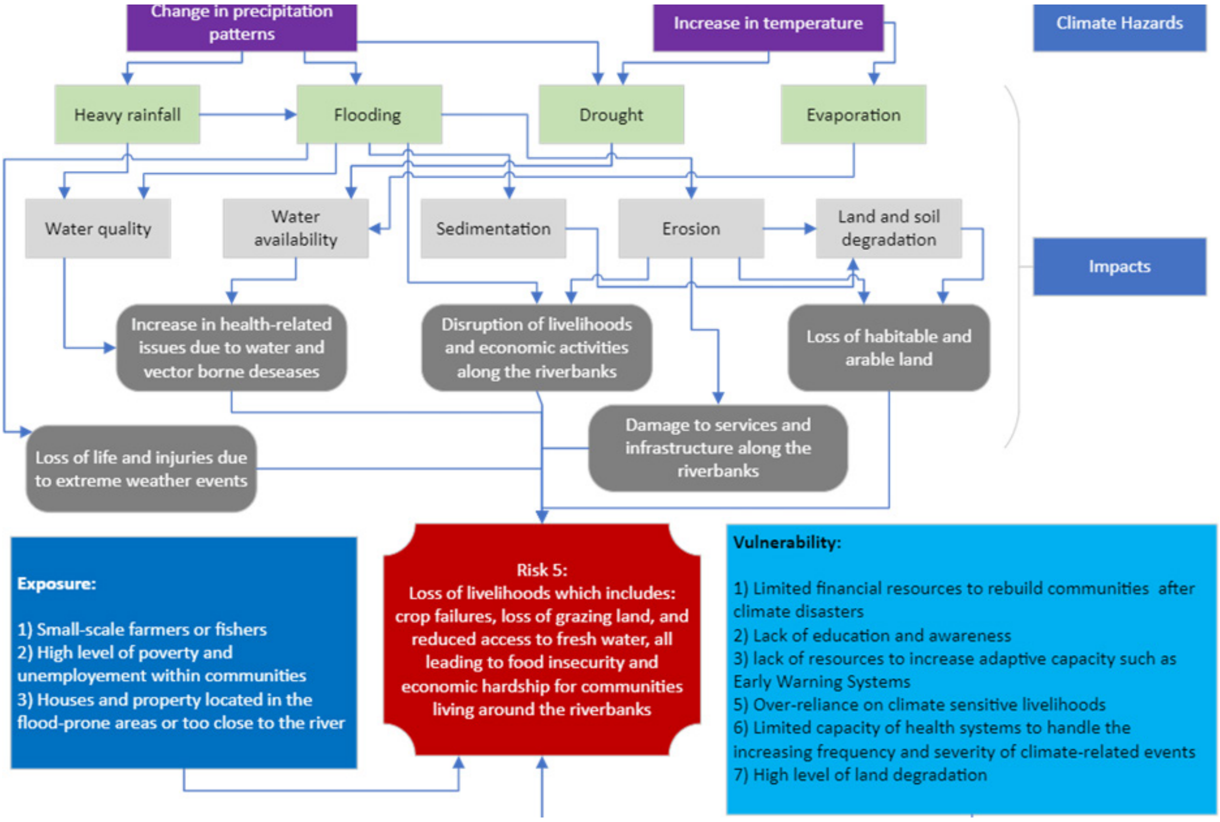
Climate change impacts will be experienced through: decreased water quality and quantity, high rates of land degradation, erosion and sedimentation which affects livelihoods by reducing water available for farming and domestic uses, increasing water- and vector-borne diseases, damaging infrastructure and disrupting services along the riverbanks, loss of arable and habitable land which in turn affects the socioeconomic activities in the region, and lastly, an increase in injuries and loss of life.

These impacts will disproportionately affect women and girls who are often responsible for domestic and subsistence activities, including water collection, food production and subsistence agriculture.

The reduction in water availability and increased water- and vector-borne diseases will increase the workload of women and girls and limit their opportunities for income-generating activities and education.

Additionally, women and girls in vulnerable communities face additional gender-specific barriers, such as limited access to finance, technology, and decision-making power, which can further limit their adaptive capacity and resilience to climate change impacts and loss of livelihoods.

Figure 44 l Loss of Livelihoods Impact Chain Diagram

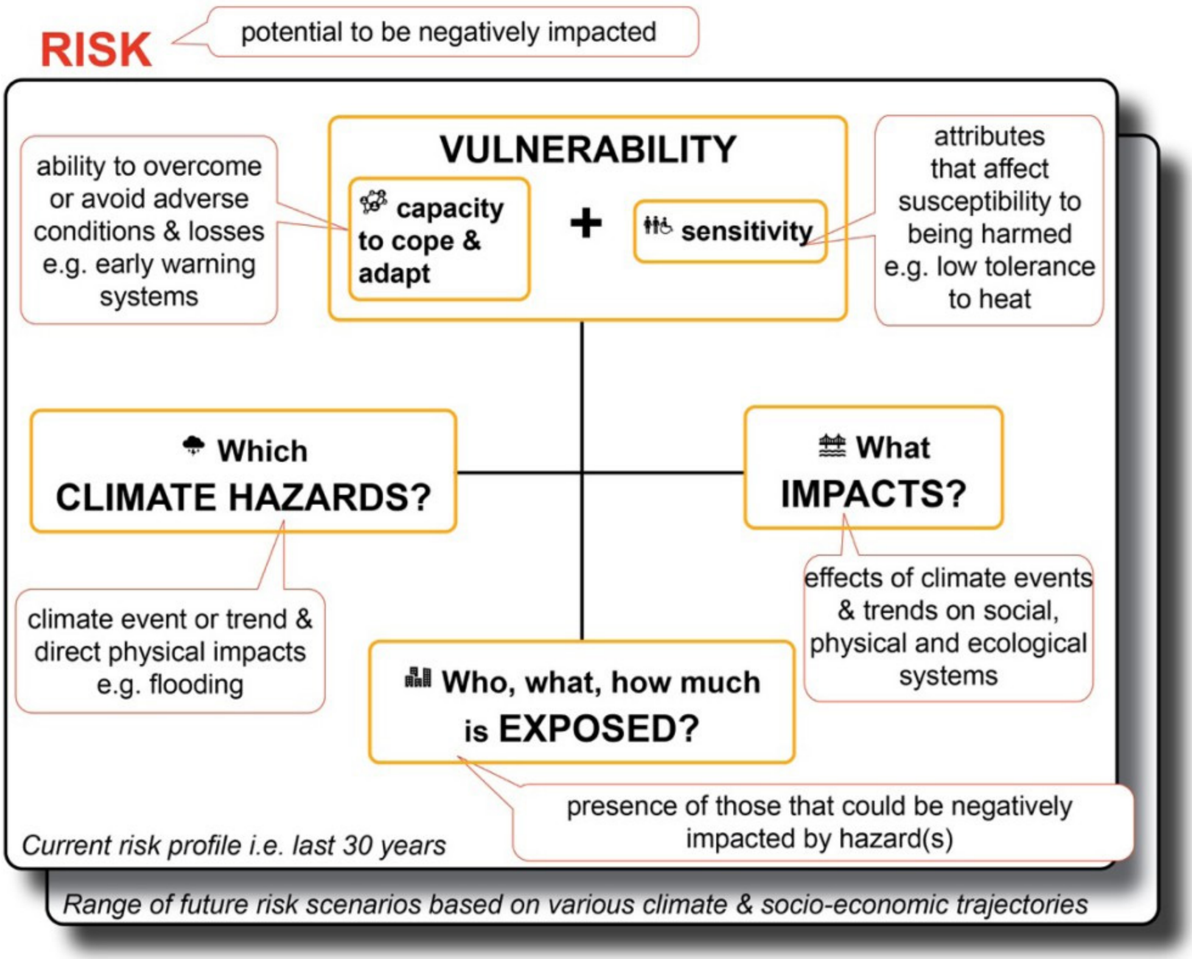


8.4 Risk Assessment Methodology

To assess key climate risks to the communities, a high-level, qualitative risk assessment was undertaken based on the understanding of risk, as provided in the IPCC's Fifth Assessment Report (AR5) (2014), where risk is a core concept, and vulnerability is a component of risk.

The key step in understanding risk is identifying who and what is exposed to the climate hazards and might therefore be impacted or harmed, that could be adversely affected (Department of Environment, Forestry and Fisheries, 2020). An illustration of this definition of risk used, is shown in Figure 45.

Figure 45 I The component of climate vulnerability and climate risk, adapted from IPCC AR5



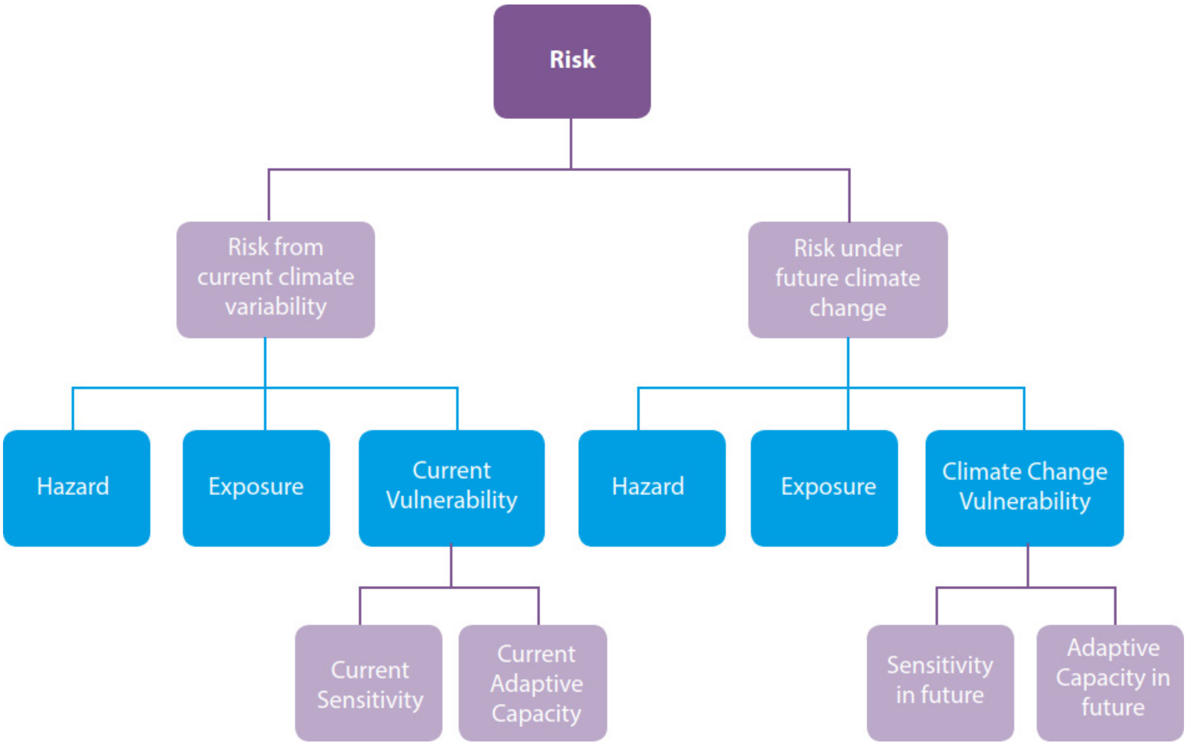
In this study, the risk is defined as a function of HAZARD (H), EXPOSURE (E) and VULNERABILITY (V), and assessed as probable harm that can be caused to a biophysical or socioeconomic system by an anticipated threat. The approach to risk assessment involved collating and analysing information from stakeholder consultations and literature, considering the three elements that result in risk, where:

$$Risk = f(H, E, V)$$

The assessment involved:

- Hazard identification and characterisation.
- Exposure characterisation.
- Assessing the systems' vulnerability.
-

Figure 46 | Climate change risk assessment variables



8.4.1 Climate Change Hazard

The level of hazard is determined either directly from individual climate change parameters, such as temperature and precipitation, or from derived variables such as changes in drought frequency, extreme rainfall events, mean annual runoff, impact on water supply, heat stress, or crop productivity. The severity of potential impact is then characterised in terms of thresholds, as shown in Table 18.

Table 18 | Climate hazard thresholds used to characterise the severity of potential impacts

Climate Hazard	Climate change parameter used	L[1]	M[1]	H[1]	VH[1]
Temperatures	Change in Mean Temperatures	0°C	+ 1°C	1.5°C	2°C
Precipitation	Change in Mean Annual Rainfall	100	50	0	-50
Droughts	Change in SPEI	2	1	0	-1
Floods	Change in maximum daily rainfall	-10%	-5%	0%	5%
Wildfires	Change in extreme temperatures	0%	10%	50%	100%
Agriculture	Change in crop suitability		-	-	–
Livestock	Change in heat index (HI)/max temperature	0%	10%	50%	100%
Human Health	Change in heat index (HI)/max temperature	0%	10%	50%	100%

L - Low M - Moderate H - High VH – Very High

Some of the values for the above variables can be derived directly from climate risk maps (for example changes in mean annual temperature or precipitation), or from derived hazard maps such as are shown below, in terms of drought hazard and water resource availability (Figure 31), and crop suitability for primary crops grown in Ghana under different climate change scenarios (Figure 33).

The criteria to define the magnitude of the hazard is included in **Appendix D**.

8.4.2 Exposure

The exposure to critical hazards such as increasing flood risk can be supported by hazard mapping, as mentioned above, with regard to the flood hazard mapping study for Ghana and the Roadmap for Resilient Infrastructure in a Changing Climate Report. These maps can be used to determine the exposure for people or infrastructure. The results of these analyses showed that the people's or assets' exposure to flood risk does not necessarily significantly increase with climate change, but the frequency and magnitude of these might change, driven primarily by changes in extreme rainfall events.

Exposure was analysed by evaluating the history of past and recent weather events in TaMA. Where there was not enough secondary data to establish the exposure, information gathered during the stakeholder engagement was used to complement the quantitative indicators, such as the estimate of the number of people or buildings located in flood-prone areas.

The criteria to determine the level of exposure is included in **Appendix D**.

8.4.3 Vulnerability

Vulnerability is conceptualised as an integral part of a system or of an asset that is a function of its current insufficient adaptive capacity to overcome the adverse impact of a climate hazard and its sensitivity.

The purpose at this stage is to identify vulnerability conditions based on exposure, and on the sensitivities and adaptive capacities. Vulnerability can be defined as a composite of two aspects of sensitivity and capacity. Sensitivity includes the physical environment, and socioeconomic or cultural dynamics.

As the first step, a participatory approach was adopted, to profile sectors within TaMA. The profiles exhibit the general status quo, including the biophysical and socioeconomic status of the catchment. It is important to note that climate change vulnerability is not only dependent on climate-related hazards but, to a large extent, on socioeconomic factors. It has been established that climate change will exacerbate the existing socioeconomic problems within TaMA.

Vulnerability was analysed using the feedback from the stakeholder engagement and on a review of published sources. Adaptive capacity was estimated by determining the abilities of the systems in place, or missing, to reduce or minimize the impacts of climate risks. Capacity aspects such as knowledge, technology, economy, and institutions, were considered in assessing the climate vulnerability.

Vulnerability is expressed as:

$$\text{VULNERABILITY} = \text{SENSITIVITY} - \text{ADAPTIVE CAPACITY}$$

The criteria to assess sensitivity and adaptive capacity respectively, as well as the matrix used to assess and categorise the level of vulnerability for each system or asset, are included in **Appendix D**.

8.4.4 Evaluating Priority Risk

The final risk evaluation involved combining the results that reflect the situation of the different components that comprise it. The assessment of the potential risk that climate change will have on natural and human systems, was done through applying the matrix of hazard, exposure and vulnerability.

The risk assessment matrix makes it possible to rank exposure and vulnerability. It also helps to identify the priorities, systems and sectors at risk (Fall, Correa, & Sarr, 2011).

The matrix used to rank the potential risks of the hazards associated with climate change on natural and human systems, is based on exposure to identified climate hazards and on the vulnerability of key natural systems, socioeconomic sectors and local livelihoods. The matrix is included in **Appendix D**.

8.5 Risk Assessment Results

8.5.1 Current and Future Climate-Related Risks

The risk assessment was intrinsically participatory and based on the approach elaborated on under Section 8.4, and the conceptual framework presented in Figure 35. Understanding the risks at a local level requires an integrated approach that looks at both the climate hazards and social dimensions of vulnerability. The stakeholders were engaged to identify the assets and systems exposed to climate change risk, and shared their perspectives and experiences of the climate events that had adversely affected their systems of interests, and the challenges that they had to face as a result of such events.

While the stakeholders engaged were representative of different groups, it is not always possible to identify all critical risks. This section therefore likely only represents a selection of the most critical risks.

The engagement sessions revealed that the population seems to be interested in, and aware of, climate change issues, and are prepared for disasters, as the following actions are already being implemented:

- There are disaster volunteer groups in every community that have been trained on what to do in the event of a disaster. They have a communication protocol to follow. However, there has been a challenge in recruiting volunteers because they don't receive payment. The National Disaster Management Organisation (NADMO) did indicate that this is being addressed under a new initiative.
- There is an effective health communication system.
- Forestry personnel collaborate well with forest-fringe communities and have protocols in place.
- Forest-fringe community members have been trained in basic firefighting skills.
- People with disabilities are always included in engagements and have a good working relationship with government officials.

- The Right to Information Act, 2019 (Act 989) is in place, which is important for the dissemination of information. The Act provides for the implementation of the constitutional right of persons to access official information held by public institutions and some private entities.
- There is a Toll-Free line for urgent cases (disasters) which receives priority.
- The Ghana Safety Net Project has mapped the communication systems at different levels, as per the image below (see Appendix 2 for more information).

During the workshop there was a suggestion that an improvement can be made on the reporting of the Ghana Meteorological Agency (GMet) weather information to communities. This is only reported on television or accessible on smartphones. There are challenges with disseminating the information further, but this would be it would be beneficial to do so as it could assist with early warning to communities of flooding, heat waves, etc. Headway has been made with recent projects sponsored by the World Bank focused on developing and implementing real-time climate information services to agricultural workers (Damba, et al., 2021)and flood studies (Triple Line Consulting Limited, 2022).

The discussions with stakeholders led to the results presented in Table 19 and Table 20 below.

8.5.2 Adaptive Capacity and Residual Climate Risks

Tamale is located in a region considered to be vulnerable to climate and weather extremes, including high summer temperatures, floods, droughts and bushfires. Climate change projections for Tamale suggests increasing average and maximum temperatures and heatwave events, increased rate of evaporation, and a higher risk of wildfires. However, there is disagreement amongst climate models on future changes to seasonal and annual precipitation levels and intensity, suggesting a high level of uncertainty, with some models projecting increases and others decreases. Several adaptation options can however be considered that could reduce the risk for all possible future climate change scenarios.

According to the assessment of climate change related risks, climate risk mitigation measures (adaptation) can reduce some elements of risk, such as sensitivity, and enhance adaptive capacity. Reducing risk requires modification of current policies and programs and implementation of policies that explicitly consider climate variability and climate change. The proposed adaptation measures focus more on reducing the sensitivity and enhancing the capacity, hence building a more resilient system. The resulting residual climate change risk assessment results for different assets and risk domains, are presented in Table 21 below, ranking current, future and residual, from low to the extreme.

Based on the results of the analysis of current and future climate risks and qualitative considerations of the sensitivity, exposure and vulnerability, this CCRA has identified several critical climate-related risks for Tamale (see Table 22). The identified risk under the current and future conditions are rated high to extreme, but with the suggested risk mitigation measures, the level of risk is expected to reduce.

Table 19 | Assessment of current climate change risks

Asset	Hazard Description	H	E	HxE	AC	S	V	Comment: Impacts	CCR
Damage to water treatment plant	Precipitation increase and flooding. Excess water due to the spillage of the Bagre Dam. The intake dam risk exceeds its maximum level. Increased sedimentation also affects the treatment plant negatively.	High	High	High	Medium	Very High	High	Water supply was affected, water quality issues (pH from the farms and sedimentation) affecting the health of the communities (cholera outbreak).	**High**
Water supply system	Water scarcity when supply is affected by drought or rains coming later than usual. Damage to water supply infrastructure due to floods and storms, leading to water unavailability. Failure to meet water supply demands during the drought seasons.	High	Medium	High	Medium	High	High	Water scarcity has led to an increased risk of waterborne diseases in Tamale, as water quality was affected, which in turn affected the health of communities (i.e. cholera outbreaks). Rate of evaporation has increased, exacerbating water scarcity issues.	**High**
Water resources	Flooding, riverbanks erosion.	Medium	Medium	Medium	Low	High	High	Damage to infrastructure: fluvial flooding has damaged bridges and other forms of infrastructure, which is costly to repair and has disrupted lives of the communities, their livelihoods, and transportation. In some cases, people were forced to leave their homes due to flash floods, leading to homelessness and other social disruptions.	**High**
Communities living along riverbanks	Fluvial flooding.	High	High	High	Very low	High	Extreme	Fluvial flooding has damaged infrastructure and property around the riverbanks, leading to financial losses for individuals and communities and disrupting people's livelihoods.	**Extreme**
Urban stormwater management	Flash floods have become a common phenomenon over the past four years. It was reported that residents were trapped in flood waters after three hours of downpour on 30 August 2021 in Tamale.	High	High	High	Low	High	High	Flooding has damaged roads, bridges, and other forms of infrastructure, which can be costly to repair, affecting the general population, women and children, and people with special needs.	**High**
Road infrastructure	Urban flooding, river flooding, poor road infrastructure. Flooding of roads and bridges and waterlogging significantly impact accessibility.	High	High	High	Low	High	High	Flooding can damage roads, bridges, and other forms of infrastructure, which can be costly to repair and disrupt transportation and communication. Children, people with disabilities, and the older population, are the most affected.	**High**
Agricultural land-crop productivity	Heavy precipitation causing waterlogging, patterns and distribution of rainfall has changed, and decreased. Dry spells have become more frequent.	High	High	High	Low	High	High	Decline in agricultural production due to waterlogging, causing food insecurity and affecting the most vulnerable groups within society.	**High**

Asset	Hazard Description	H	E	HxE	AC	S	V	Comment: Impacts	CCR
Fisheries - rivers	Farms become submerged under water and sedimentation has increased.	Medium	Medium	Medium	Very low	Very High	Extreme	Decline in fish production, affecting livelihoods.	**High**
Health systems	Increased numbers of stagnant water bodies and temperatures have resulted in an increase in reports of malaria cases in Tamale. One health government official reported that over the past season they have required double the amount of medication to cover the increased number of cases, as well as repeat cases of malaria.	Very High	Very high	Extreme	Low	Very High	Extreme	Increase in temperatures and numbers of stagnant water bodies has resulted in increased reports of malaria, affecting children more than any group within the communities.	**Extreme**
Agricultural (crops and livestock)	2017 outbreak of army worm due to increase in minimum temperatures and precipitation. Overall increase in pests and diseases in crops and livestock.	High	High	High	Very low	Very High	Extreme	Agriculture production had been affected by the army worm and other pests and invasive species outbreaks in Tamale, leading to food insecurity and loss of livelihoods.	**Extreme**
Forestry	Bushfires are reported to have been particularly bad over the past 10 years with 1 in every 3 plantations being burnt (stakeholders). Deforestation.	Medium	Medium	Medium	Medium	High	High	Deforestation leads to the severe impact of gusts/strong winds on settlements because there are no trees to act as a buffer. Bushfires threaten human life and has resulted in injuries to people who were caught in the path of fires.	**High**
Human health	Increased cases of malaria during the rainy season. Air pollution due to bushfires, causing respiratory diseases.	Medium	High	High	Low	High	High	Malaria and respiratory diseases have increased, affecting people with chronic illnesses, and children.	**High**
Education	Heavy rainfall can make roads unpassable, and fear of flooding and safety of school children during heavy rains.	High	High	High	Low	High	High	Disruption of education programmes due to heavy rains.	**High**
Settlements	Strong winds: deforestation has removed natural buffers and communities have reported increased winds that destroy their property, together with more dust and respiratory/health issues.	Medium	High	High	Very low	High	Extreme	Loss of property, leaving people homeless, and affecting livelihoods and businesses.	**Extreme**

H: Hazard Score **E: Exposure** **AC: Adaptive Capacity** **S: Sensitivity** **V: Vulnerability** **HxE: Hazard x Exposure**

CCR: Climate Change Risk

Table 20 I Assessment of future climate change risks

Asset	Hazard Description	H	E	HxE	AC	S	V	Comment: Impacts	CCR
Water treatment plant	There is a possible trend, although not significant, towards increased return values for the wettest years, indicating the prospects of increased flood risks.	Very high	Very high	Extreme	Low	High	High	Water supply was affected. Water quality (pH from the farm and sedimentation) affecting the health of the communities (cholera outbreak).	Extreme
Water supply systems	Precipitation is highly variable. However, the CMIP6 projections projected wetter conditions over Tamale, and yet there is high confidence that temperatures are expected to increase under both CMIP5 and CMIP6. Increase in temperature will likely increase the rate of evaporation and therefore affect water availability and lead to water scarcity. Climate change will also intensify the magnitude and the frequency of extreme weather events.	Very high	High	Extreme	Low	High	High	Water scarcity can lead to an increased risk of waterborne diseases, as people may resort to using unsafe water sources if clean sources are unavailable. Water scarcity can also lead to conflicts over access to water, as different groups may compete for limited supplies. This can lead to social and political tensions within communities. Water scarcity can have economic impacts, as it can lead to a decline in agricultural productivity.	Extreme
Water sources, rivers	The expected changes in precipitation patterns will likely lead to fluvial flooding. While there are no clear trends in return values for the driest annual events, suggesting limited change in drought occurrences and magnitudes, the precipitation patterns, when combined with an increasing trend in average annual temperatures, could result in an increasing risk of drought.	High	High	High	Low	Moderate	High	Damage to infrastructure: fluvial flooding can damage bridges and other forms of infrastructure, which can be costly to repair and disrupt transportation and communication. Erosion can undermine the foundations of buildings and other structures, making them more susceptible to collapse. In some cases, people may be forced to leave their homes due to erosion, leading to homelessness and other social disruption. Erosion can negatively impact the environment by destroying habitats and disrupting ecosystems.	High
Communities along riverbanks	The expected changes in precipitation and temperatures may lead to floods, drought and storms.	High	Very high	Extreme	Very Low	High	Extreme	Fluvial flooding can damage homes and other forms of property around the riverbanks, leading to financial losses for individuals and communities, and disrupting people's livelihoods. The damage caused by flooding can have significant economic impacts, including losses in agriculture, industry, and other sectors.	Extreme
Urban storm-water management	There is a possible trend, although not statistically significant, towards increased return values for the wettest years, thus indicating the prospects of increased flood risks.	Very high	Very high	Extreme	Very Low	High	Extreme	Flooding can damage roads, bridges, and other forms of infrastructure, which can be costly to repair.	Extreme
Road infrastructure	There is a possible trend, although not statistically significant, towards increased return values for the wettest years, thus indicating the prospects of increased flood risks.	Very high	Very high	Extreme	Very Low	Medium	High	Damage to infrastructure: flooding can damage roads, bridges, and other forms of infrastructure, which can be costly to repair and disrupt transportation and communication. Children, people with disabilities and the older population are the most affected.	Extreme
Agricultural land - crops	Precipitation patterns may change, and floods, drought events and extreme weather events may increase in future.	Very high	High	Extreme	Very Low	High	Extreme	Decline in agricultural production due to waterlogging.	Extreme
Fisheries - along rivers	Projected wetter conditions in Tamale may lead to the increased risk of fluvial flooding.	High	Very high	Extreme	Very Low	High	Extreme	Decline in fish production.	Extreme

Asset	Hazard Description	H	E	HxE	AC	S	V	Comment: Impacts	CCR
Health systems	The projected wetter conditions (on average) and increase in temperatures are likely to increase risk of vector-borne and waterborne diseases. Increasing flood risks could damage critical infrastructure and limit access to hospitals and other healthcare facilities.	Very high	Very high	Extreme	Low	High	High	Increase in temperatures and numbers of stagnant water bodies will result in increased cases of malaria.	Extreme
Agricultural	The expected changes in precipitation and temperatures may lead to floods, drought and storms affecting food production and leading to food insecurity. Water Scarcity risk may also increase and thus affect irrigation.	Very high	High	Extreme	Low	Medium	High	Pests can cause significant damage to crops and other plants, reducing yields and potentially leading to crop failures. Pest infestations can result in economic losses for farmers and industries that rely on agricultural production. Pests can also negatively impact the environment by reducing biodiversity and disrupting ecosystems. Some pests, such as ticks and mosquitoes, can transmit diseases to humans, negatively impacting public health.	Extreme
Forestry	Temperatures are expected to increase in future leading to increased risk of Bushfires.	High	High	High	Low	Medium	High	Removal of trees can disrupt the local ecosystem, leading to changes in the water cycle, soil erosion, and habitat loss for plants and animals. Removal of trees contributes to the greenhouse effect and warming of the planet. Deforestation leads to the severe impact of gusts/strong winds on settlements because there are no trees to act as a buffer. Bushfires can pose a threat to human life and can result in injuries to people who are caught in the path of the fire. Bushfires can cause damage to homes, businesses and other property.	High
Human health	Temperatures and the intensity and frequency of heat waves are expected to increase in future leading to increased risk of Bushfires that may cause respiratory related health issues.	High	Very high	Extreme	Low	Very high	Extreme	Higher temperature and heat stress could result in a greater number of people at risk of heat-related medical conditions. Bushfires may cause respiratory-related health issues. Bushfires destroy valuable medicinal plants.	Extreme
Education	Precipitation and extreme rainfall events may increase in future, leading to floods.	High	High	High	Very Low	Medium	High	Disruption of education programmes due to heavy rains.	High
Settlements	Increase in extreme events such as storms and heavy precipitation and strong winds, may lead to floods and damage to properties.	High	High	High	Very Low	Very high	Extreme		Extreme

H: Hazard Score **E: Exposure** **AC: Adaptive Capacity** **S: Sensitivity** **V: Vulnerability** **H x E : Hazard x Exposure** **CCR: Climate Change Risk**

Table 21 I Assessment of future residual risk after implementation of adaptation measures

		Residual Risk assessment				
Asset	**Adaptation Measures**	**Adaptive capacity**	**Sensitivity**	**Exposure**	**Vulnerability**	**Residual Risk**
Water treatment plant	1. Develop and strengthen early warning systems for floods, droughts, and water scarcity 2. Upgrade treatment plant and processes to handle changing climate related risk 3. Conduct a more detailed climate risk assessment on the infrastructure 4. Improve the resilience and capacity of infrastructure to cope with extreme weather events	Medium	High	Medium	High	High
Water supply systems	1. Develop and implement water conservation and management strategies 2. Develop and strengthen early warning systems for floods, droughts, and water scarcity 3. Conduct a more detailed climate risk assessment on the infrastructure 4. Improve the resilience and capacity of infrastructure to cope with extreme weather events	Medium	High	Medium	High	High
Water sources, rivers	1. Implement integrated catchment water conservation and management strategies 2. Develop and strengthen early warning systems for floods, droughts, and water scarcity	Medium	Low	Medium	Medium	Medium
Communities living along riverbanks	1. Diversify livelihood sources and income streams to reduce the sensitivity of climate risk 2. Promote climate-resilient crops and agricultural practices 3. Promote the development of alternative livelihoods 4. Strengthen social safety nets and support systems 5. Enhance capacity building and training in climate-resilient practices 6. Foster community-based natural resource management	Medium	Low	Medium	Medium	Medium
Urban stormwater management	1. Upgrade stormwater management systems	High	Moderate	Medium	Medium	Medium

Road infrastructure	1. Improve the drainage systems to handle increased rainfall 2. Use of porous pavements to reduce runoff and improve water quality 3. Retrofit bridges and culverts to improve resilience to extreme weather events 4. Implement early warning systems for natural disasters 5. Integrate climate change considerations into road design and planning processes	High	Moderate	High	Medium	High
Agricultural land - crops	1. Promote climate-resilient crops and agricultural practices, including small-scale irrigation 2. Enhance capacity building and training in climate-resilient practices, targeting vulnerable people 3. Improve access to climate information and knowledge on climate change impacts 4. Develop insurance schemes and risk mitigation tools for agriculture sector 5. Enhance the governance of climate-sensitive resources	Medium	High	Low	High	Medium
Fisheries - along the rivers	1. Diversify livelihood sources and income streams to reduce the sensitivity of communities to climate risk 2. Promote the development of alternative livelihoods 3. Enhance capacity building and training in climate-resilient practices 4. Foster community-based natural resource management	Medium	High	Medium	High	High
Health systems	1. Strengthen health infrastructure and emergency preparedness 2. Develop and implement early warning systems for disease outbreaks 3. Enhance community health and engagement 4. Promote environmental health and sustainability 5. Integrate climate change into health policies and programs	Medium	High	Medium	High	High

Agricultural (crops and livestock)	1. Promote climate-resilient crops and agricultural practices 2. Enhance capacity building and training in climate-resilient practices 3. Improve access to climate information and knowledge on climate change impacts 4. Develop insurance schemes and risk mitigation tools for agriculture sector 5. Enhance the governance of climate-sensitive resources	Medium	Medium	Medium	Medium	Medium
Forestry	1. Implement REDD+[11] policies 2. Enhance capacity building and training in climate-resilient practices 3. Foster community-based natural resource management	High	Medium	Medium	Medium	Medium
Human health	1. Develop insurance schemes and risk mitigation tools 2. Implement early warning systems for natural disasters	High	Medium	Medium	Medium	Medium
Education	1. Strengthen early warning systems 2. Improve access to climate information	Medium	Low	Medium	Medium	Medium
Settlements	1. Strengthen early warning systems 2. Improve access to climate information 3. Develop insurance schemes and risk mitigation tools	Medium	Medium	Medium	Medium	Medium

11 REDD' stands for 'Reducing emissions from deforestation and forest degradation in developing countries. The '+' stands for additional forest-related activities that protect the climate, namely sus tainable management of forests and the conservation and enhancement of forest carbon stocks.

Table 22 I Climate change risk assessment results matrix and short narrative explaining the risk

Critical System	Risk description	Current Risk	Future Risk	Residual Risk
Water treatment plant	There is a possible trend, although not significant, towards increased return values for the wettest years, indicating the prospects of increased flood risks. The current water treatment plant is located close to the river and could be damaged due to floods.	High	Extreme	High
Water supply systems	Precipitation is highly variable. However, the CMIP6 projections projected wetter conditions over Tamale, and yet there is high confidence that temperatures are expected to increase under both CMIP5 and CMIP6 projections. Increase in temperature will likely increase the rate of evaporation and therefore affect water availability and lead to water scarcity. Climate change will also intensify the magnitude and the frequency of extreme weather events and likely contribute to increased variability of rainfall.	High	Extreme	High
Water sources, rivers	The expected changes of precipitation patterns will likely lead to fluvial flooding. While there are no clear trends in return values for the driest annual events, suggesting limited change in drought occurrences and magnitudes, the precipitation patterns, when combined with an increasing trend in mean annual temperatures, could result in an increasing risk of drought.	High	High	Medium
Communities living along riverbanks	The expected changes in precipitation and temperatures may lead to floods, drought and storms.	Extreme	Extreme	Medium
Urban stormwater management	There is a possible trend, although not statistically significant, towards increased return values for the wettest years, thus indicating the prospects of increased flood risks.	High	Extreme	Medium
Road infrastructure	There is a possible trend, although not statistically significant, towards increased return values for the wettest years, thus indicating the prospects of increased flood risks.	High	Extreme	High
Agricultural land - crops	Precipitation patterns may change, and floods, drought events and extreme weather events may increase in future.	High	Extreme	Medium
Fisheries - along the rivers	Projected wetter conditions in Tamale could lead to the increased risk of fluvial flooding.	High	Extreme	High
Health systems	The projected wetter conditions and increase in temperatures are likely to increase risk of vector-borne and waterborne diseases.	Extreme	Extreme	High
Agricultural (crops and livestock)	The expected changes in precipitation and temperatures may lead to floods, drought and storms affecting food production and leading to food insecurity. Water scarcity risk may also increase and thus affect irrigation. Increasing temperatures will contribute to reduced productivity of livestock and reduced water availability and fodder, affecting both crops and livestock.	Extreme	Extreme	Medium
Forestry	Temperatures are expected to increase in future, leading to increased risk of bushfires.	High	High	Medium
Human health	Temperatures are expected to increase, leading to increased risk of bushfires that may cause respiratory-related health issues.	High	Extreme	Medium
Education	Mean annual precipitation and extreme rainfall events may increase in future, leading to floods.	High	High	Medium
Settlements	Increase in extreme events such as storms and heavy precipitation may lead to floods and damage to properties.	Extreme	Extreme	Medium

9

Conclusion and Recommendations

9.1 Future Climate Change Scenarios for TaMA

Future climate change projections show that there is a risk of significantly higher temperatures for Tamale by mid-century, even at lower GHG concentration scenarios, with an expected increase of 2ºC, varying from 1.5ºC up to 4ºC by the end of the century, depending on the emission scenario. Precipitation projections, in contrast, carry large uncertainties. There is a slightly greater chance of small increases, typically around 5%, in annual average precipitation, in the north, compared to the base years, during the first half of this century. There is also a relatively significant chance of decreases in precipitation to a similar degree. By the end of the century, either an increase or decrease in mean annual precipitation appears possible, as the extremes suggest that a change in precipitation is possible of up to +/-15/20%. The latest CMIP6 climate change scenarios are considered to be much more sensitive and suggest a much greater probability for overall wetting in the Northern Region of Ghana, with some scenarios suggesting up to a 20% increase in the mean annual precipitation by mid-century. This requires further research to verify.

Heavy precipitation events will become more likely in the future, especially under the high emission scenario, as maximum daily rainfall is expected to increase under all scenarios, but particularly under CMIP6, with the greatest increase, of around 20%, in maximum daily rainfall, under SSP5-8.5. Increases in the number of very hot days, and days with a high heat index, could double for TaMA, and this will have a very serious impact on human and livestock health, as well as increased fire and water security risks.

Given the likely reduced impact on precipitation, particularly with the latest global climate models, it is likely that, while still a concern, the risk from increasing severity of drought is reducing overall for Ghana.

9.2 Priority Climate Related Hazards and Risks

For TaMA, eight first and second order priority risk domains were identified that have a significant number of climate change hazards associated with them. These include the following:

- Water Resources (surface water)
- Fluvial Flooding
- Droughts
- Fire Risk
- Water Security (water and sanitation)
- Agriculture – Crop Productivity
- Agriculture – Livestock Productivity
- Health (heat stress, diseases, etc.)

Based on these priority risk domains, the following critical climate-related issues/risks were identified by key stakeholders during a multi-stakeholder workshop held in Tamale on 23 November 2023.

- Precipitation patterns may change, and floods, droughts and extreme weather events may increase in the future, affecting food production (agricultural sector), leading to food/water insecurity.
- The most prominent climate hazards for TaMA are extreme heat and inland flooding.
- The critical systems that were identified with high sensitivity and/or low adaptive capacity, as well as high exposure to extreme heat, include health and forest systems, since temperatures are expected to increase in future, leading to increased risk of bushfires that may cause respiratory-related health issues. In addition, increases in temperature will likely increase the rate of evaporation and therefore affect water availability, leading to increased water scarcity.
- The water supply system (including the water treatment plant), which is a critical infrastructure, is highly exposed to inland flooding, and with a high sensitivity and low adaptive capacity, poses a risk not only to water scarcity, but also to the health sector, since this leads to an increased risk of waterborne diseases as people may resort to using unsafe water sources if clean sources are unavailable. Increasing water scarcity and damage to water infrastructure can also lead to conflicts over access to water, as different groups compete for limited supplies.
- Urban areas, as well as the transport infrastructure, are also highly exposed to inland flooding, with a high sensitivity and/or low adaptive capacity. The damage caused by flooding can have significant economic impacts, including losses in agriculture, industry and other sectors. Flooding also disrupts the access to crucial systems such as health and education, where people with disabilities, women, children and the older population, are the most affected.
- In many cases the communities most exposed, and with limited adaptive capacity, are those located in peri-urban or informal areas where there is also a lack of basic infrastructure.

9.3 Climate Change Risk Assessment Results

Based on the review of future climate scenarios and the engagement with key stakeholders, impact chain diagrams were developed for the priority hazards and risks identified above. These were then used to evaluate both the current and future level of risk as a function of hazard, exposure and adaptive capacity. For each of these priority risk domains, potential adaptation options were considered, and their potential impact on reducing the overall climate-related risks were determined as a residual risk.

Following the consideration of potential adaptation options, the critical systems with the highest residual risk, and therefore considered to be important for prioritising adaption responses, were:

- Potential flood risk to the water treatment plant (and other critical infrastructure), as well as the impacts of upstream catchment degradation and sand mining on water quality.
- Overall impact on water resource availability and water supply infrastructure.
- Damage to road infrastructure and disruptions due to increased urban flooding risk.
- Impact on health systems, including damage to hospitals and access to health facilities.
- Impact on crop productivity and livestock health.
- Impact on fisheries (rivers) due to more variable flows and higher sediment loads.

9.4 Potential Adaptation Options and Recommendations

The Ghanaian Government has been investing in the integration of climate change objectives and priorities into sector-specific development plans in agriculture, transportation and energy, to mainstream climate change strategies and to co-ordinate the strategic climate adaptation activities, in line with the country's socioeconomic development objectives. In the Fourth National Communication, Ghana is particularly focused on increasing its resilience through the development of sustainable land use practices, climate-proof infrastructure, water security, energy security, sustainable forest management, and urban waste management. It is evident that there is a need to adapt to the future unpredictable climate. Investing in capacity building, and education on climate risks, as well as the dissemination of information, was found to be a crucial component for a successful climate change adaptation strategy for Tamale. Additional actions needed to address priority risks and vulnerabilities due to climate change were identified in various studies and risk assessments undertaken in the last decade.

Below is a non-exhaustive list of adaptation options from the various previous studies and policy documents consulted by the Project Team, which could improve the residual risk level for TaMA:

- **General Adaptation Response Priority Projects for critical infrastructure**
  - **Energy Sector:**
    - Resilient and green energy access in drought-prone districts
    - Capacity development and regulatory frameworks to support local renewable energy generation, including solar energy, to enhance resilience of remote, vulnerable communities
    - Update energy sector design standards to incorporate climate adaptation risk
  - **Water Sector:**
    - Water supply resilience through regional harvesting and storage solutions
    - Climate adaptation alignment across water ministries, and planning mechanisms to ensure integrated water resource management
    - Proactive risk-informed asset management
  - **Transport Sector:**
    - Supporting resilient design and construction of roads through research, capacity building, and the creation of a design manual
    - Climate risk-informed asset management system and operations and maintenance practices for roads
    - Airport flood resilience through elevation of runways and other vulnerable components
    - Bridges and underpasses to ensure community access to services
  - **Agricultural Sector:**
    - Ensure affordability and financial sustainability of crop and livestock insurance products[12], such as weather index insurance (this measure will mostly increase resilience of vulnerable

12 New low-cost index-based crop and livestock insurance packages are becoming increasingly available. An example: [Ghana's farmers arm against freak weather with crop insurance | PreventionWeb]

communities to climate-related risks, in addition to increasing investments that can raise agricultural productivity)

- Invest in improved post-harvest management systems
- Improve water management, and explore potential for irrigation upscaling, including by upscaling the use of solar irrigation
- Facilitate setting up of rainwater harvesting structures for small-scale irrigation by building on existing maps, to identify potential areas for groundwater development for small-scale irrigation
- Increase investment in local breeding of improved crop varieties and improve dissemination of higher quality/robust seeds
- Improve land and soil management strategies, including integrated soil fertility management, to reduce erosion and degradation of soils

– **Urban planning:**

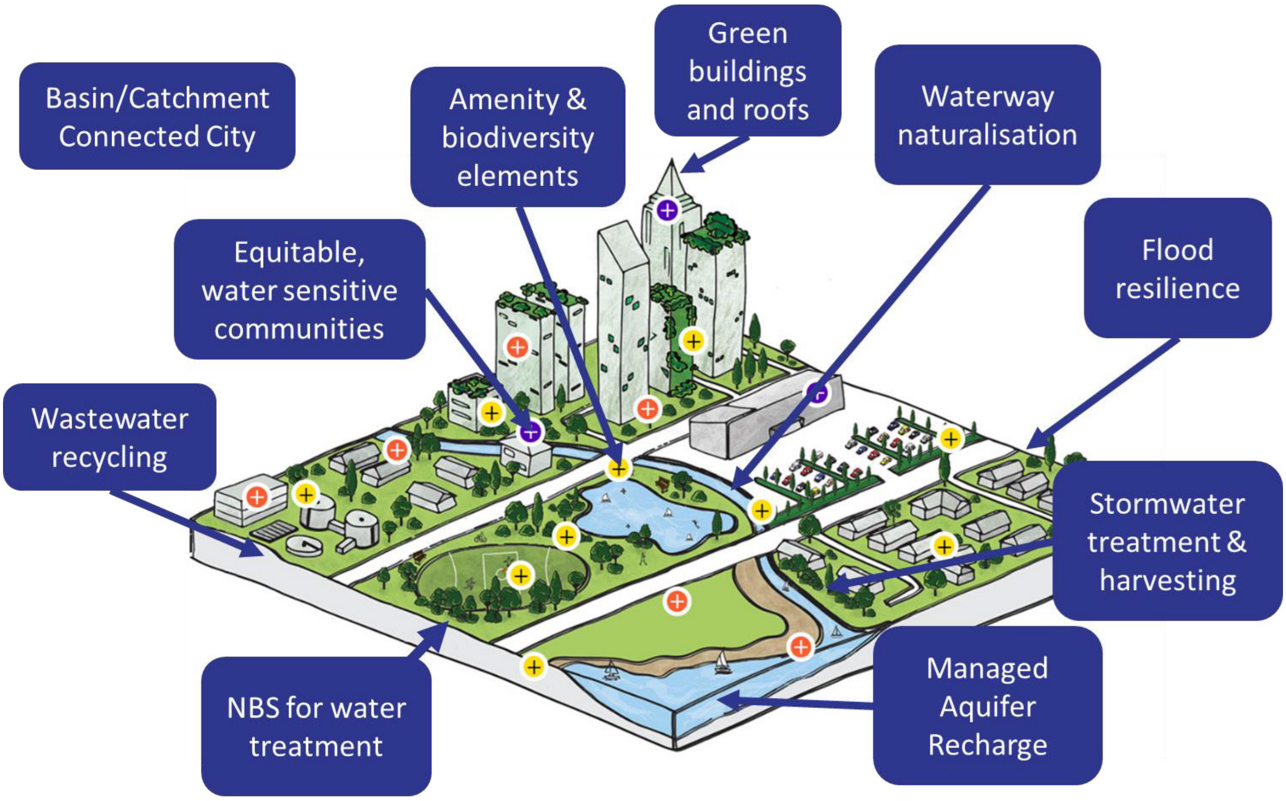
- Development of an overall drainage plan that is consistent with the Greater Tamale Structure Plan and that identifies the low-lying areas and the locations of outfalls and main drains, and considers future population and land use
- Develop, broadcast, and enforce zoning guidelines or other local regulations, to ensure encroachment on flood prone areas is avoided

– **Cross-sectoral:**

- Upstream afforestation of the Volta River reservoir to build resilience to flood and drought
- Centralised climate-risk data management system
- Mainstream resilience through climate risk assessments and EPA permitting process and strengthen enforcement for all infrastructure projects
- Gender mainstreaming in adaptation planning, implementation and management
- Prioritise nature-based solutions in planning, design and operation of infrastructure

Underlying many of these proposed interventions is the need to support the transition of Tamale to becoming a more Water Sensitive City (see Figure 47), for example by developing approaches to increase urban flooding resilience, as this will help in addressing many of the existing climate-related risks and help to improve liveability and productivity for Tamale. Key to supporting the transition to a Water Sensitive and Low Carbon City, is developing a strategy and identifying champions, as well as putting in place the necessary information and tools to help with integrated urban planning.

Figure 47 I Components of a Water Sensitive City



Source: CRC for Water Sensitive Cities

Several other initiatives are already underway, and must be supported, which will also help in improving climate resilience for Tamale. Some of these identified existing initiatives include:

- Flood risk analysis for priority catchments within TaMA and plans to produce an updated stormwater master plan, and to improve the existing drainage capacity.
- A study on the potential for establishing a Water Fund to improve catchment management and to reduce the impact of sand mining, which are threatening water security for TaMA.
- Providing climate information and implementing climate-smart agriculture (CSA) in Ghana.

The process of enhancing adaptive capacity cuts across all adaptation activities regardless of the approach. There are generally considered to be five key components to assessing adaptive capacity that should be outlined within an adaptation policy framework, shown in Figure 48. These criteria should be considered when identifying priority actions for adapting to climate change in Tamale.

Figure 48 I Outline framework for developing adaptive capacity

1. Scoping and designing an adaptation project: what is the adaptive capacity and the capacity enhancement goal?	• A project should identify the priority system, the hazards and the timescale at which these hazards are likely to occur • Consider the project's adaptation objective
2. Assessing current vulnerability: what adaptive capacity already exists to reduce existing vulnerabilities?	• Addressing existing hazards will support longer-term adaptation strategies • Use of qualitative indicators to develop an adaptive capacity baseline
3. Assessing future climate risks: what capacity will the City have to adapt to future hazards?	• Adaptive capacity to a set of hazards may be enhanced or reduced over time, depending on development pathways • Engage stakeholders to create an environment where adaptation and climate change information can be disseminated
4. Formulate an adaptation strategy: what policies enhance adaptive capacity and encourage autonomous adaptation?	• Designing policies that identify trade-offs, synergies and conflicts between key sectors • Raising awareness, identifying and prioritising adaptation options and removing barriers are the principle elements of capacity development
5. Continuing adaptation: how can adaptive capacity enhancement efforts be sustained and improved?	• Reviewing, monitoring and evaluating to maintain levels of adaptive capacity and recognising opportunities for mainstreaming adaptation • Establishing processes to identify where capacity development has succeeded/failed and where it can be translated into actual adaptation actions

Source: Modified from Berger et al. (2014)

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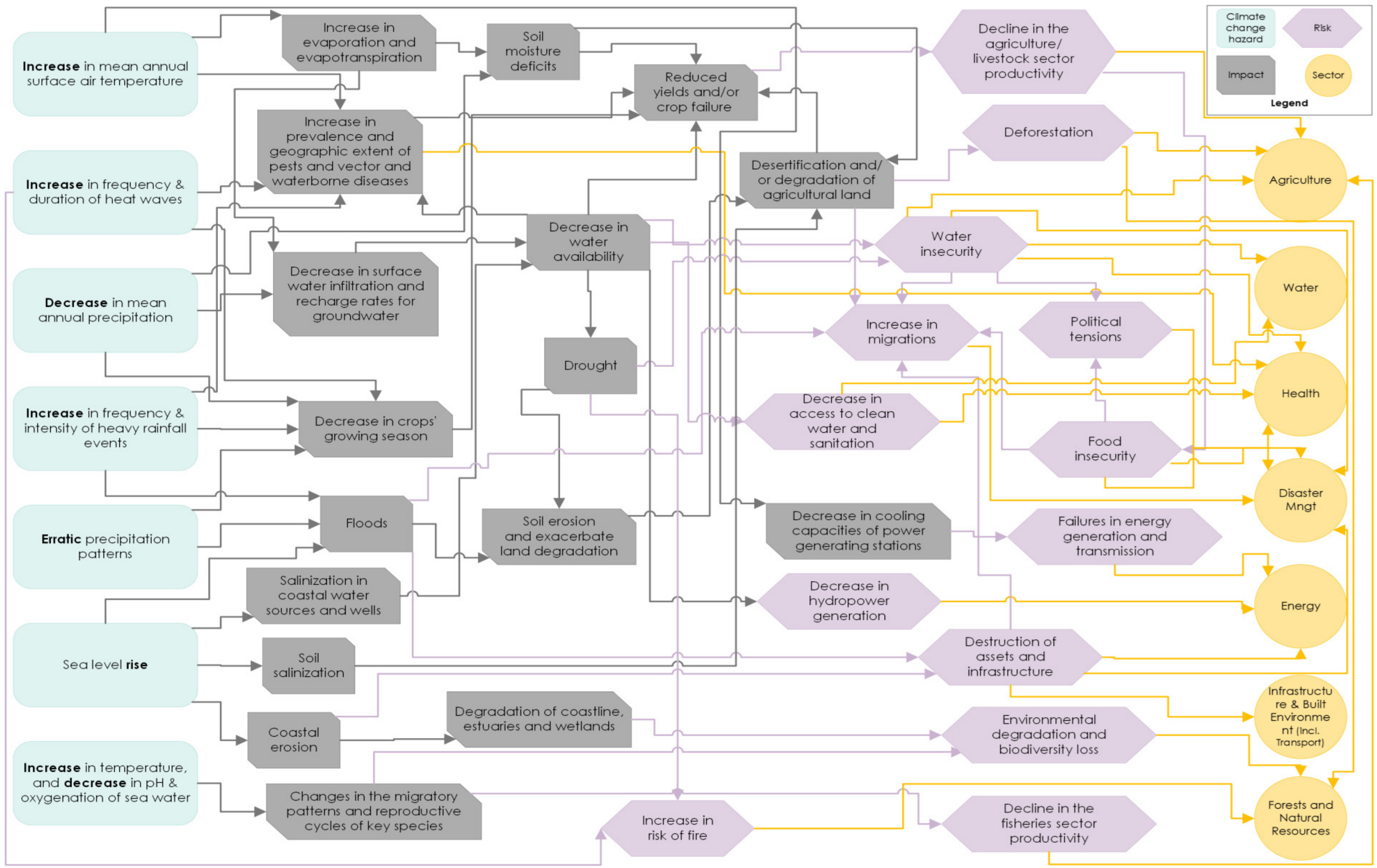
Appendix A I Generic climate hazard impact chain for key risks in Ghana

Figure A. 1 I Impact chain diagram for selected climate hazards and risk domains relevant for use at the MMDA level in Ghana



Appendix B I Stakeholder Engagement

B1 I Invitation and Stakeholder List - Tamale

Tel: (03720) 22294
Email: northern.region@epa.gov.gh
Website: http://www.epa.gov.gh

Environmental Protection Agency
P. O. Box TL 620
Tamale
Northern Region

EPA/NR/25/Vol.1

24th November, 2022

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Dear Sir/Madam,

INVITATION TO A ONE (1) DAY STAKEHOLDERS CONSULTATION MEETING ON THE NATIONAL ADAPTATION PLAN FOR CLIMATE CHANGE MITIGATION

The Environmental Protection Agency (EPA) under the auspices of the Ministry of Environment Science Technology and Innovation (MESTI), is coordinating the national Adaptation Planning (NAP) process with technical and financial support from the Climate Fund (GCF) through the United Nations Environment Programme (UNEP). The NAP Project seeks to build the resilience of local communities through effective climate change adaptation.

The project has identified Tamale and Sekondi-Takoradi for a compressive risk assessment for the dry land conditions and coastal zone, respectively. The assessment will inform the development of adaptation plans for the two metropolises. Stakeholder consultation is one of guiding principles of the NAP Process.

Against the backdrop of this principles, a team of personnel from UNEP is embarking on a stakeholder consultation mission in Tamale Metropolis of the Northern region.

The venue and time for the stakeholder engagement is as follows;

Venue: Catholic Guest House, Tamale
Date: Tuesday 29th November, 2022.
Time: 8:30 am prompt

You are kindly required to nominate one (1) person from your outfit to participate in this very important stakeholder engagement meeting to be held in the Northern region

We apologies for the short notice

Counting on your usual cooperation.

Yours faithfully,

Abu Iddrisu
(Regional Director)
For: Executive Director

CLIMATE CHANGE ENGAGEMENT – STAKEHOLDERS – NORTHERN REGION: 28TH – 29TH NOVEMBER, 2022

1. The Hon. MCE	-	Tamale Metropolitan Assembly
2. The Regional Director	-	MoFA, Tamale – Northern Region
3. Regional Economic Planning Office	-	REPO. RCC – Tamale
4. The Regional Director	-	FSD, Tamale – Northern region
5. The Regional Director	-	Ghana National Fire Service
6. The Director	-	GDCA – Tamale –Northern region
7. The Head of Department	-	Department of Climate Change – UDS – Tamale
8. The Regional Director	-	Regional House of Chiefs, Tamale, N/R
9. The Director,	-	ACDEP Secretariate, Tamale , N/R
10. The Regional Director	-	Catholic Relief Service, Tamale, N/R
11. The Executive Director	-	Peasant Farmers Association, Tamale, N/R
12. The Regional Director	-	Irrigation Development Authority, Tamale, N/R
13. The Regional Director	-	Department of Gender, RCC, Tamale, N/R
14. The Regional Director	-	LUSPA, Tamale
15. The Regional Director	-	Lands Department, Tamale, N/R
16. The Regional Director	-	Ghana Productive Safety nets Project (GPSNP), Tamale.
17. The National Co-ordinator	-	GCAP Project Tamale, N/R
18. The Regional Director	-	GES, Tamale, N/R
19. The Regional Director	-	Community Development, Tamale, N/R
20. The Regional Director	-	National Population Council, Tamale, N/R.
21. The Regional Director	-	NADMO, Tamale, N/R
22. The Regional Director	-	Ministry of Health
23. The Regional Director	-	Zaam Tamale, N/R
24. The Regional Director	-	Plan Ghana, Tamale, N/R
25. The Regional Director	-	Action Aid (Ghana), Tamale, N/R
26. The Regional Director	-	CWSA, Tamale, N/R
27. The Regional Director	-	NORDA, Tamale, N/R
28. The Regional Director	-	Department of Women, Tamale, N/R
29. The Regional Director	-	GNA, Tamale, N/R
30. The Regional Director	-	RUMNET, Tamale, N/R
31. The Regional Director	-	NORSAC, Tamale, N/R
32. The Regional Director	-	WRI, Tamale, N/R
33. Dohinaa (Nomnaa)	-	Duunyin, Tamale, N/R
34. Abdul Rahman Lansah	-	(Kuko Naa) – Dolunaayilli, Tamale, N/R
35. Mac Mathia Chancellor	-	Opinion Leader, Tamale, N/R
36. Naa Abdul Latif (Sahanaa)		Opinion Leader, Tamale, N/R
37. The Regional Director	-	GBC, Tamale N/R
38. The Regional Director	-	SEND Ghana, Tamale, N/R
39. The Regional Director	-	OXFAM, Tamale, N/R
40. The Regional Director	-	NCCE, Tamale, N/R
41. The Regional Director	-	Information Services Department, Tamale, N/R
42. The Regional Director	-	Ghana Water Company Limited, Tamale, N/R
43. The Regional Director	-	Fisheries Co-operation, Tamale, N/R
44. The Regional Director	-	Feeder Roads Department, Tamale, N/R.
45. The Regional Director	-	Environmental Protection Agency, Tamale, N/R

B2 I Stakeholder List – Workshops held in Accra

7/December/2022

No.	Name	Institution
1.	Abena A. Adu	LUSPA
2.	Patience Agyekum	SYND
3.	Francisca Martey	GMET
4.	George Yorke	WaterAid
5.	Joy Hesse Ankomah	EPA-HSU
6.	Elliot Ansah	GSS
7.	Miriam Bafowaa opoku	DOR
8.	Antwi – B. Amoah	EPA
9.	Bob Manteaw	UG
10.	Eric Afornorpe	MLGDRD
11.	Evelyn Addor	Ecocare Ghana
12.	Carl Osei	GHS
13.	Joyce Gyeke	GBC
14.	David Aidoo	WaterAid
15.	Mumuni Abu	RIPS, UG
16.	Bernard Asante	VAL-Ghana
17.	Robert Mensah	MOF
18.	Foster A. Gyamfi	MOF
19.	Jonathan Gokah	Kasa Gh
20.	Joycelyn Smith	MOF
21.	Lydia Kukua Asamoah	GNA
22.	Isaac Kwabena Danso	EPA
23.	Kumi Sarfo Obed	EPA
24.	Marilyn Christian	EPA
25.	Emmanuel. A. Oduro	EPA

8/December/2022

No.	Name	Institution
1.	Abena A. Adu	LUSPA
2.	Patience Agyekum	SYND
3.	Francisca Martey	GMET
4.	George Yorke	WaterAid
5.	Joy Hesse Ankomah	EPA-HSU
6.	Elliot Ansah	GSS
7.	Miriam Bafowaa opoku	DOR
8.	Monique Cranna	ZUTARI
9.	Antwi – B. Amoah	EPA
10.	Bob Manteaw	UG
11.	Eric Afornorpe	MLGDRD
12.	Evelyn Addor	Ecocare Ghana
13.	Naa Adaku Palm	LUSPA
14.	Ishomon Foli	VALD- Ghana
15.	MaryJane Eunchill	PMU-NAP
16.	Joyce Gyeke	GBC
17.	Isabel Andam	SYND
18.	Solomon Yamoaa	YNREG
19.	Ali M. Katu	GAIP
20.	James Oppong Otoo	NADMO
21.	Angela Kwashie	UNCDF
22.	Robert Mensah	MOF
23.	Foster A. Gyamfi	MOF
24.	Jonathan Gokah	Kasa Gh
25.	Jocelyn Smith	MOF
26.	Lydia Kukua Asamoah	GNA
27.	Isaac Kwabena Danso	EPA
28.	Kumi Sarfo Obed	EPA
29.	Marilyn Christian	EPA
30.	Emmanuel. A. Oduro	EPA

Appendix C I Overview of Tamale Metropolitan Assembly (TaMA)

C1 I Location and Climate

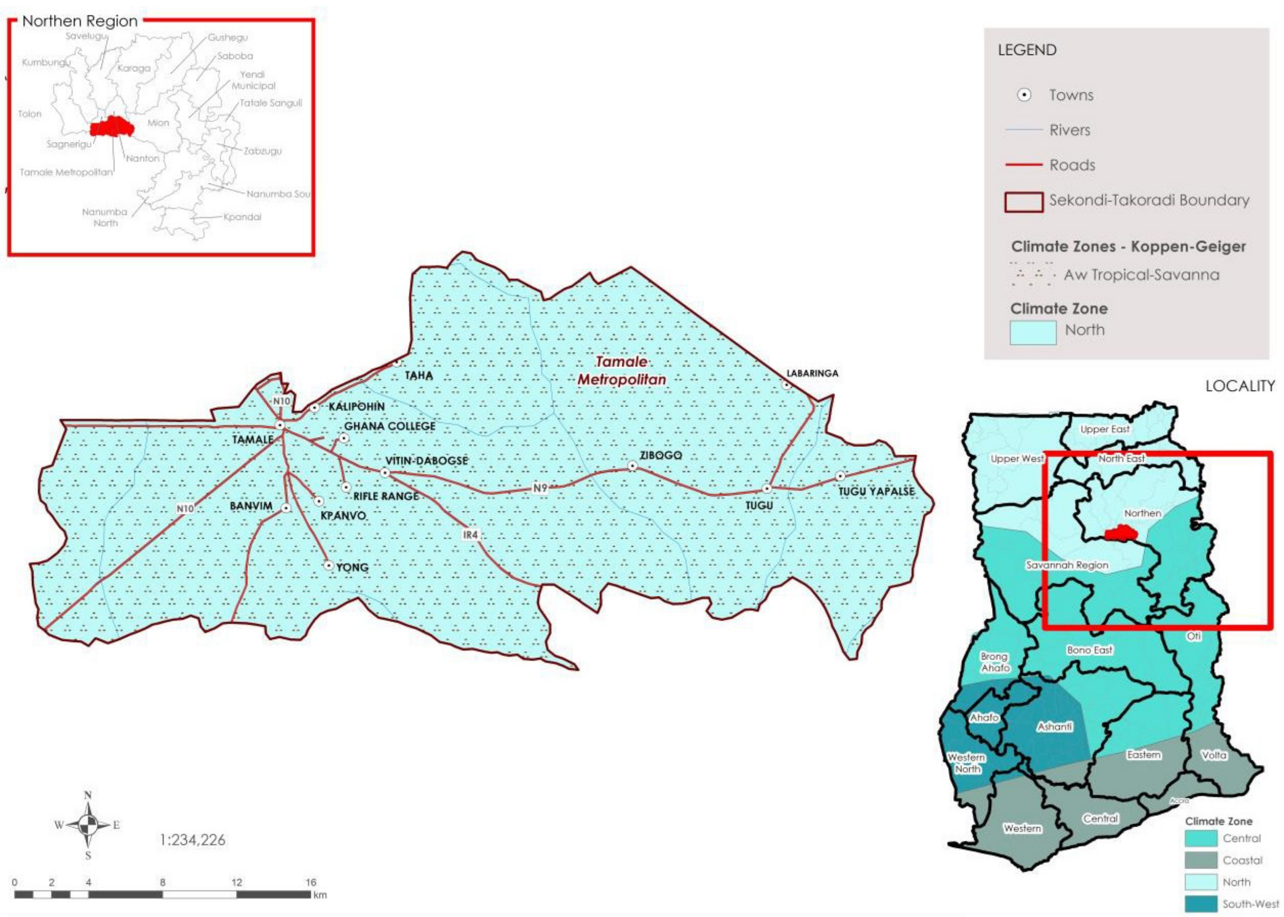
Tamale Metropolitan Assembly (TaMA) is located in the Northern Region of Ghana, at an elevation of approximately 180 m above sea level and has an area of about 650 km^2 (PHC, 2010). Tamale

Metropolitan District shares boundaries with the Sagnarigu District to the northwest, Mion District to the east, East Gonja to the south and Central Gonja to the southwest.

The location of TaMA is shown in Figure C. 1.

The four homogenous climate zones represented in Figure C. 1 were identified through the analysis of trends in observed climate data, as well as similarity in the expect changes due to climate change, during the analysis of downscaled temperature and precipitation scenarios for the periods 2030-2040, 2050-2060 and 2070-2080. As a result, they are expected to respond in a similar fashion as to future climate change under the different global emission scenarios. TaMA is located in the Northern Climate Zone of Ghana.

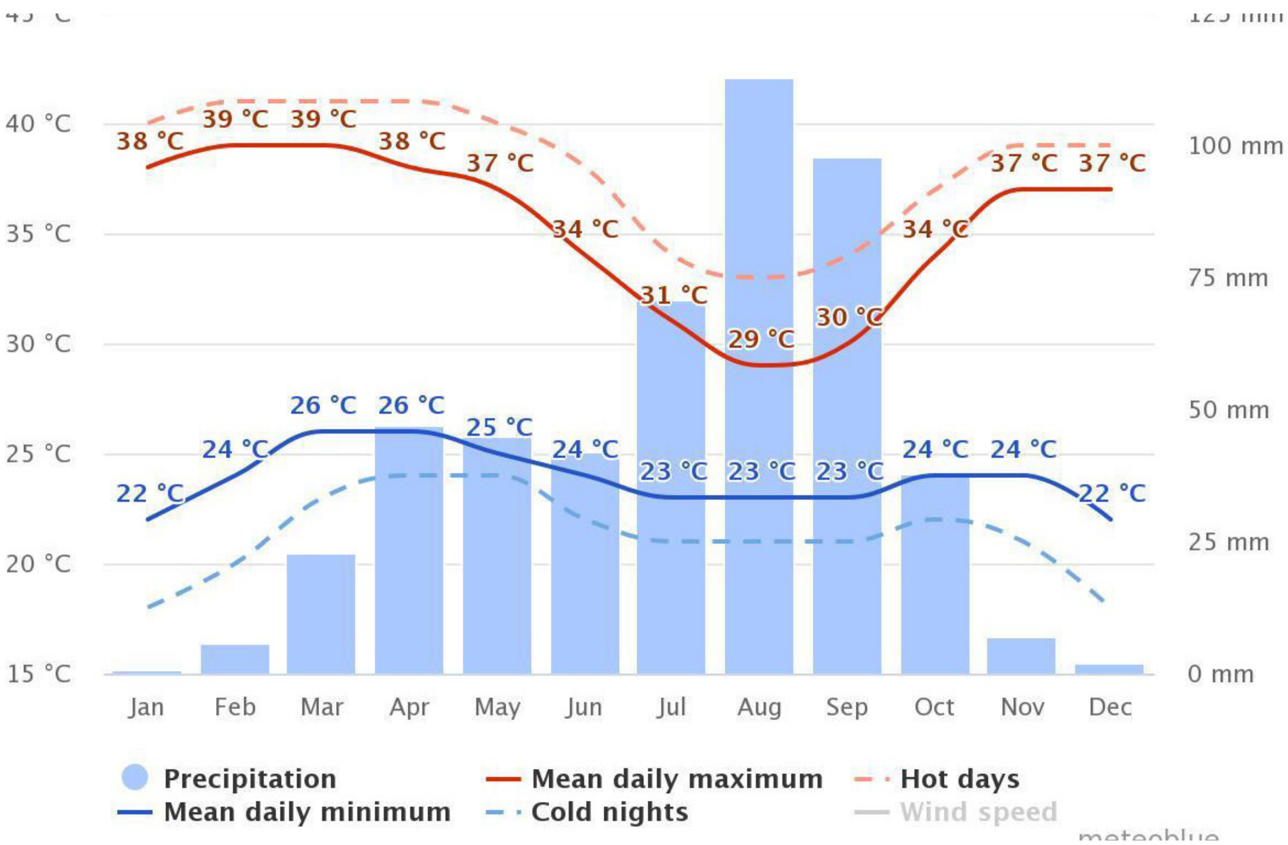
Figure C. 1 I Location and climate of TaMA



According to the Köppen-Geiger climate classification, Tamale has a tropical savannah climate, with one rainy season from April through to September or October (with a peak in July and August). The dry season is influenced by the very dry north-easterly winds (Harmattan) that blow across the West African subregion from the Sahara Desert between about October and February each year. This period of Harmattan is characterised by dry and dusty conditions, as well as wide fluctuations in the day and night air temperatures. The effect in the air of dust and sand stirred up by the wind, is known as Harmattan haze (He, Breuning-Madsen, & Awadzi, 2007).

The average annual temperature in Tamale is around 28°C. The mean daytime temperatures range from 28°C (December and mid-April) to 43°C (March, early April) , and the mean night-time temperatures range from 18°C (December) to 25°C (February, March). The mean annual rainfall is around 1100 mm within 95 days of rainfall, in the form of tropical showers (intense rainfall). The climate diagram for the average temperature and precipitation for Tamale shown in Figure C. 2, is based on 30 years of hourly weather model simulations (Source: Meteoblue.com).

Figure C. 2 I Average temperatures and precipitation, in TaMA



Source: (www.meteoblue.com, 2022)

C2 I Natural Environment

Geology, Geomorphology and Soils

The TaMA area is underlain by sandstone, mudstone and shale which, over time, have been weathered to different degrees. The main soil types include sand, clay and laterite ochrosols. These soil types are inadequately protected, resulting in serious erosion

during the rains. The area is generally flat, with gentle undulating low relief and altitude, ranging from 400 to 800 ft. above sea-level. The area has sandstone, gravel, mudstone and shale, weathered into different soil grades, as its major soil types. Owing to seasonal erosion, soil types resulting from this phenomenon are sand, clay and laterite ochrosols. The availability of the various soil types has aided rapid urban development due to sea sand, gravel and clay being used for building purposes by developers, especially in urban areas. In the rural parts, the soil type is sandy loam, and is suitable for growing crops such as millet, maize, guinea corn, groundnuts, yams and beans.

Figure C. 3 I Geology of TaMA

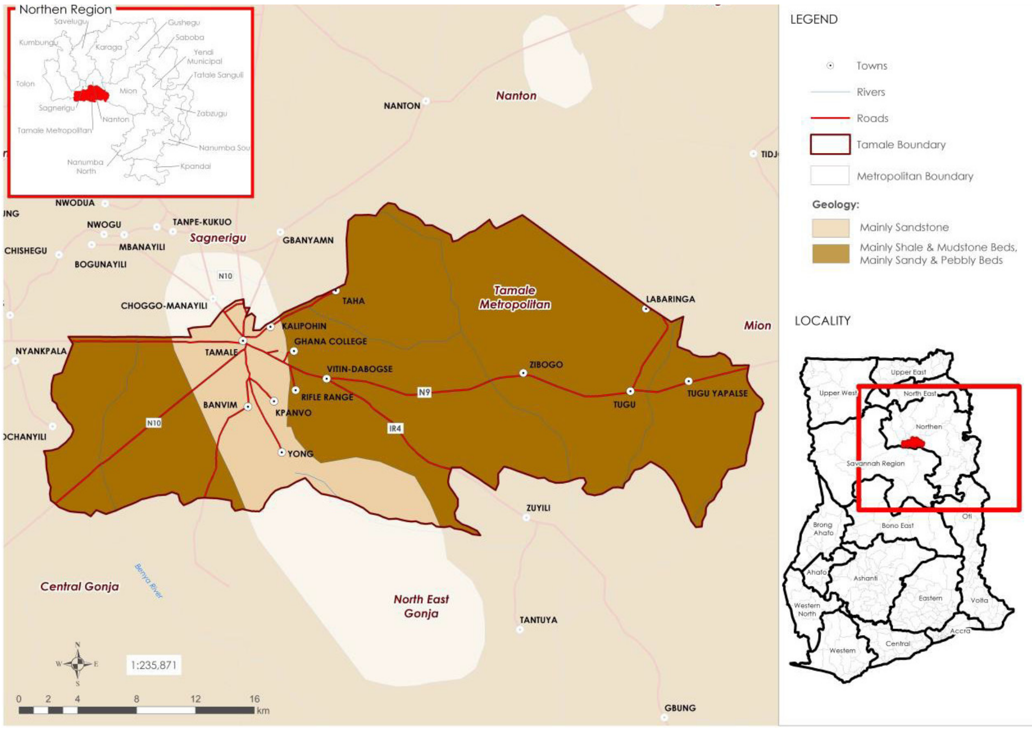
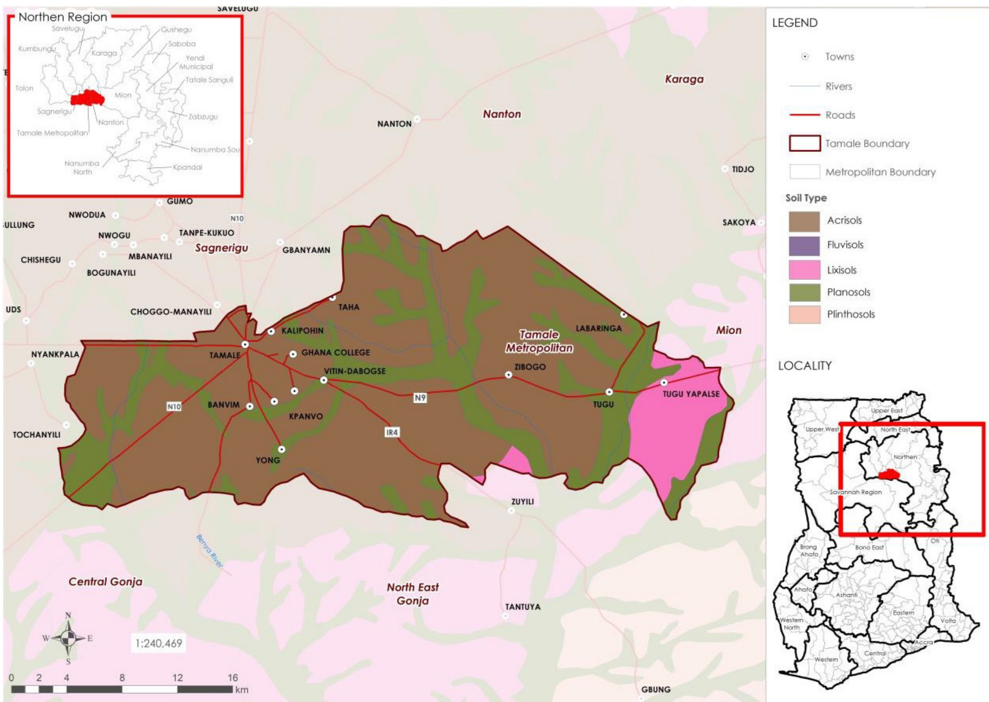


Figure C. 4 I Soil types in TaMA

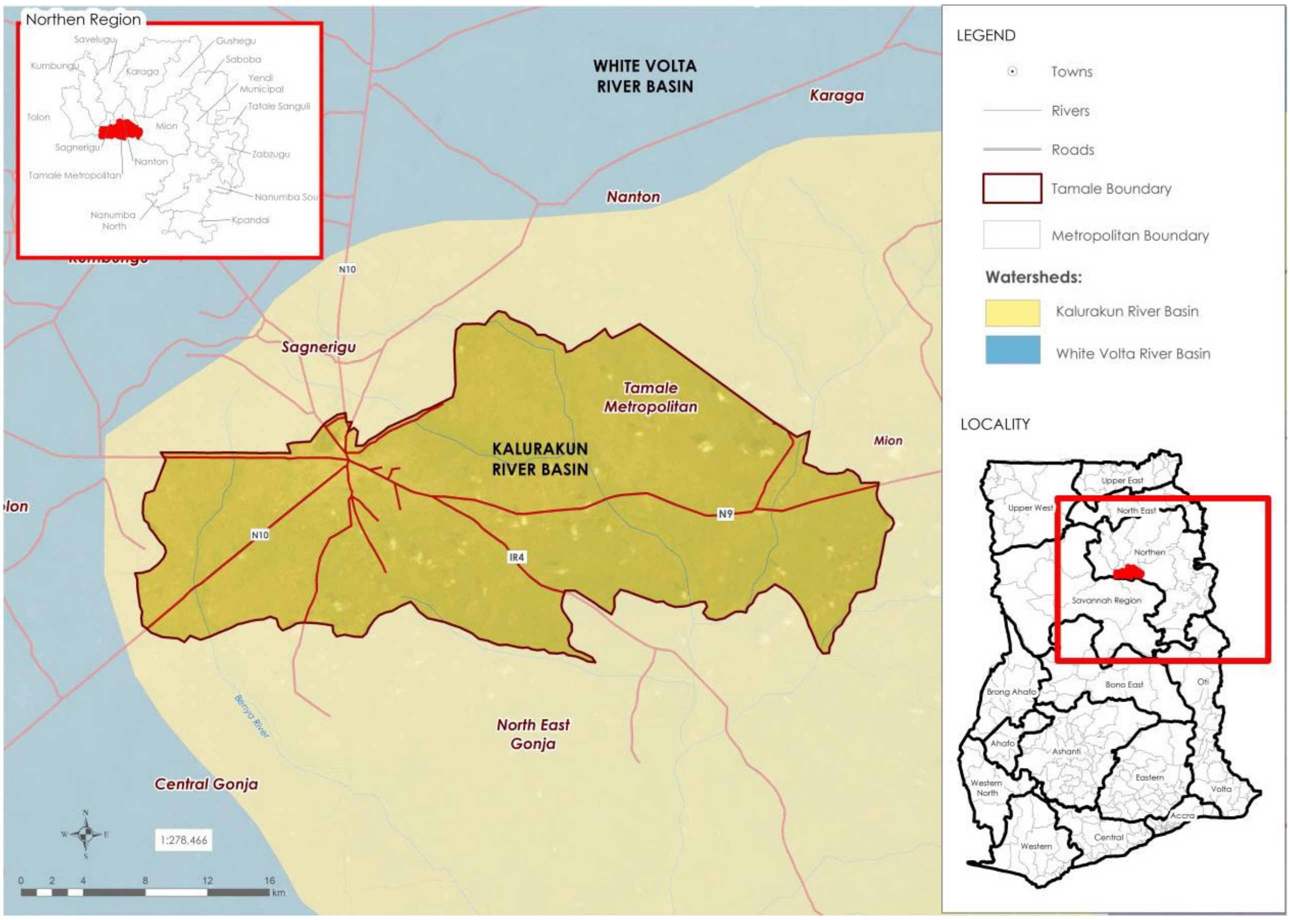


Water Resources

Ghana has three main basins that flow into the Gulf of Guinea: the Volta, Southwestern, and Coastal Basins. The transboundary Volta Basin contributes almost two-thirds of the total runoff, and is divided into the Black Volta, White Volta, Oti River, and Lower Volta, Basins. TaMA is located in the Kalurakun River Basin, which is a sub-basin of the main Volta Basin. Tamale has few water bodies. The only natural water systems are a few seasonal streams which dry up during the dry season. Tamale's water supply system extracts raw water from the Nawuni abstraction point, in the White River Basin, at about 35 km north-west of the city. Additional details on water supply are provided in the section covering Infrastructure and Services (Section C8).

The Pasam, Dirm-Nyogni and Kwaha Rivers???, in the Kalurakun River Basin, have their headwaters in Tamale. Some artificial dams and dugouts have been constructed to serve as water sources for animals as well as for domestic purposes and irrigation ((SAL Consult Ltd, 2022).

Figure C. 5 I Watersheds in TaMA



Groundwater resources are limited compared to surface water. Aquifers generally have a low productivity, limiting their viability for large-scale agriculture, municipal and industrial use. Groundwater is, however, used extensively for drinking and domestic use in rural areas, especially in northern Ghana. Naturally occurring heavy metals are present in gold mining belts in the southwest and the northwest, and naturally high fluoride levels in the north pose risks to public health. Climate change is reducing precipitation, increasing temperatures, and increasing evaporation rates in the Volta Basin, creating widespread risks to water availability across northern Ghana. (USAID/Sustainable Water Partnership (SWP), 2021)

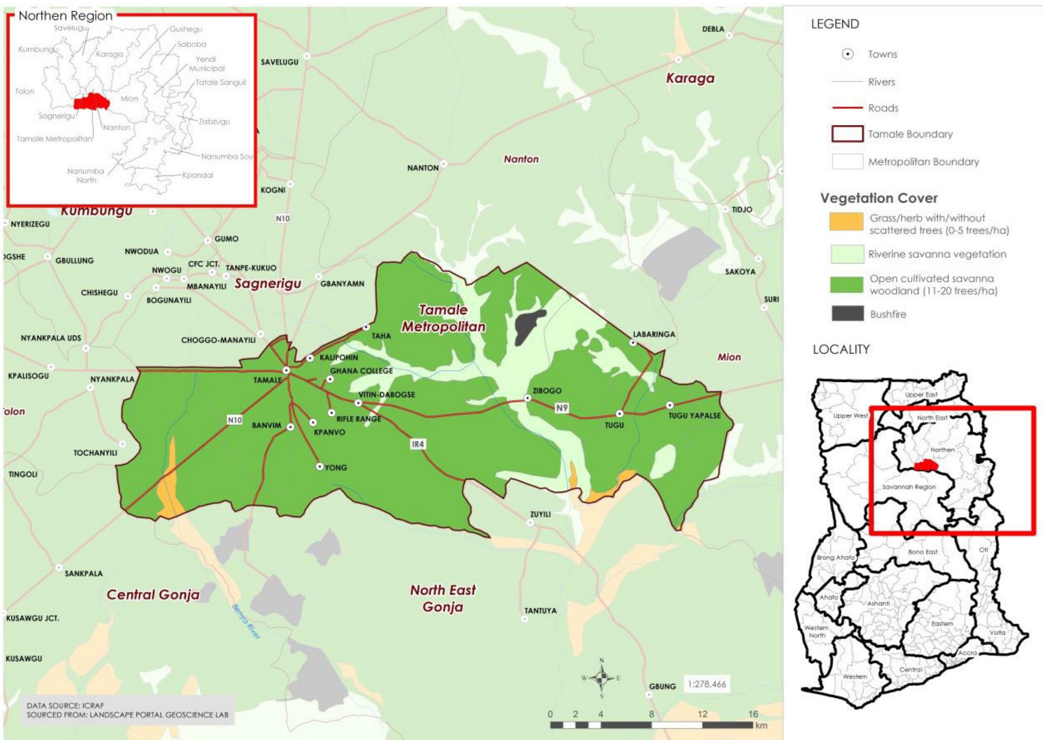
Ecosystems and Biodiversity

The Tamale Metropolitan Assembly lies within the Guinea savannah belt of northern Ghana. The vegetation of the area is characterised by tall grasses, interspersed with drought-resistant tree species such as the Dawadawa, Nim, Acacia, Mahogany and Baobab (Fuseini, 2016). The Shea and Dawadawa are the most important tree species in the area. The Shea tree forms the anchor

of women's livelihoods, either through gathering and selling of the nuts, or agro-processing by which shea-butter is extracted for cooking and for use in the cosmetic industry. The Dawadawa tree has two basic important uses, namely as a local condiment and as a symbol of authority in the chieftaincy institution of the Dagbong Kingdom (Fuseini, 2016).

A study undertaken by the Department of Forestry and Forest Resources Management of the University for Development Studies in Tamale, identified 24 forest reserves in the Northern Region, 17 of which are natural forests, while the remaining 7 are plantation reserves. The study also indicated that there are five forest districts in the region, one of them being in Tamale. The Tamale Forest District transcends the boundary of the TaMA, covering three political districts, namely the Tamale Metropolis, Savelugu-Nanton and the Tolon-Kumbungu Districts with five forest reserves. There is only one natural forest reserve in the TaMA, namely the Sinsablegbini Forest Reserve. The remainder are plantation reserves, and they are the Tamale fuelwood plantation, the Kogni plantation, the Tamale waterworks forest reserve, and the Ghana Education Service Plantation. Administratively, these five reserves are expected to serve all the communities in the three political districts, but practically, the forest fringe communities are the immediate beneficiaries (Husseini & Issifu, 2015). However, it is important to note that these reserves are being encroached upon by private developers, with other portions being used for dumping and open defecation. There are naturally occurring tall grasses that flourish during the rainy season that are woven into a mat called "Zanamat", a type of local mat for used for roofing and fencing (SAL Consult Ltd, 2022).

Figure C. 6 I Vegetation cover in TaMA, 2015

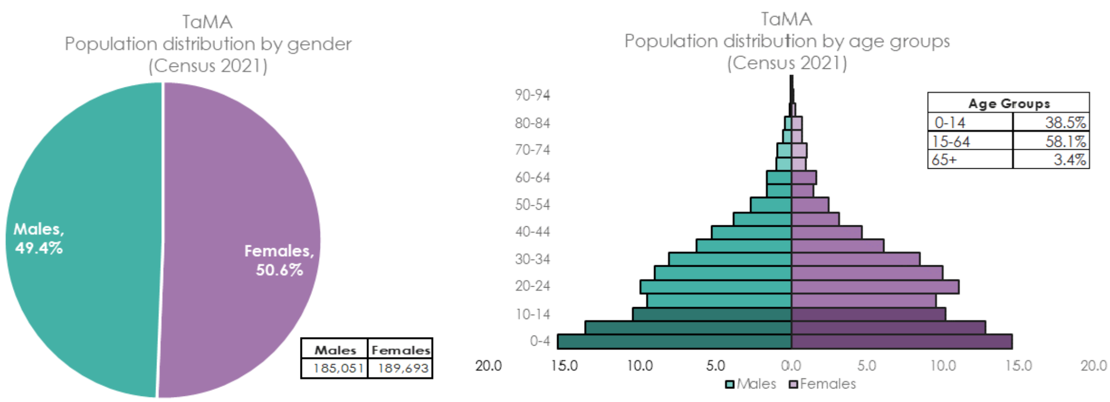


C3 I Demographics

According to the 2021 Ghana Population and Housing Census, the Tamale Metropolis had a total population of around 374,744 people, comprising 185,051 (49.4%) males and 189,693 (50.6%) females (Figure C. 7). This represents 16.2% and 1.2% of the regional and national population

respectively. The population density is 825 persons per km^2, with a total of 89,011 households, and an average household size of 4.1 persons, which is lower than the regional average of 5.2 persons per household (GSS, 2021).

Figure C. 7 I Population distribution by age and gender in TaMA



Source: Census 2021

The district has a youthful population, with about 96% being below the age of 60. The age structure of the population of a high fertility country such as Ghana, is basically shaped by the effect of mortality. As is the case with the TaMA, the structure of the population indicates a broad base that gradually tapers off with increasing age due to death. The youthfulness of the population implies a high potential for human resource development to enhance social, economic, and political development. On the other hand, the proportion of the elderly, at 4.1%, is lower than the regional and national averages of 4.5% and 5.3% respectively, which indicates a comparably low life expectancy. In this regard, pragmatic efforts would have to be made to make primary health care delivery more accessible and affordable to the aged. (2020 Composite Budget - Tamale Metropolitan). Figure C. 8 shows the population distribution within the TaMA.

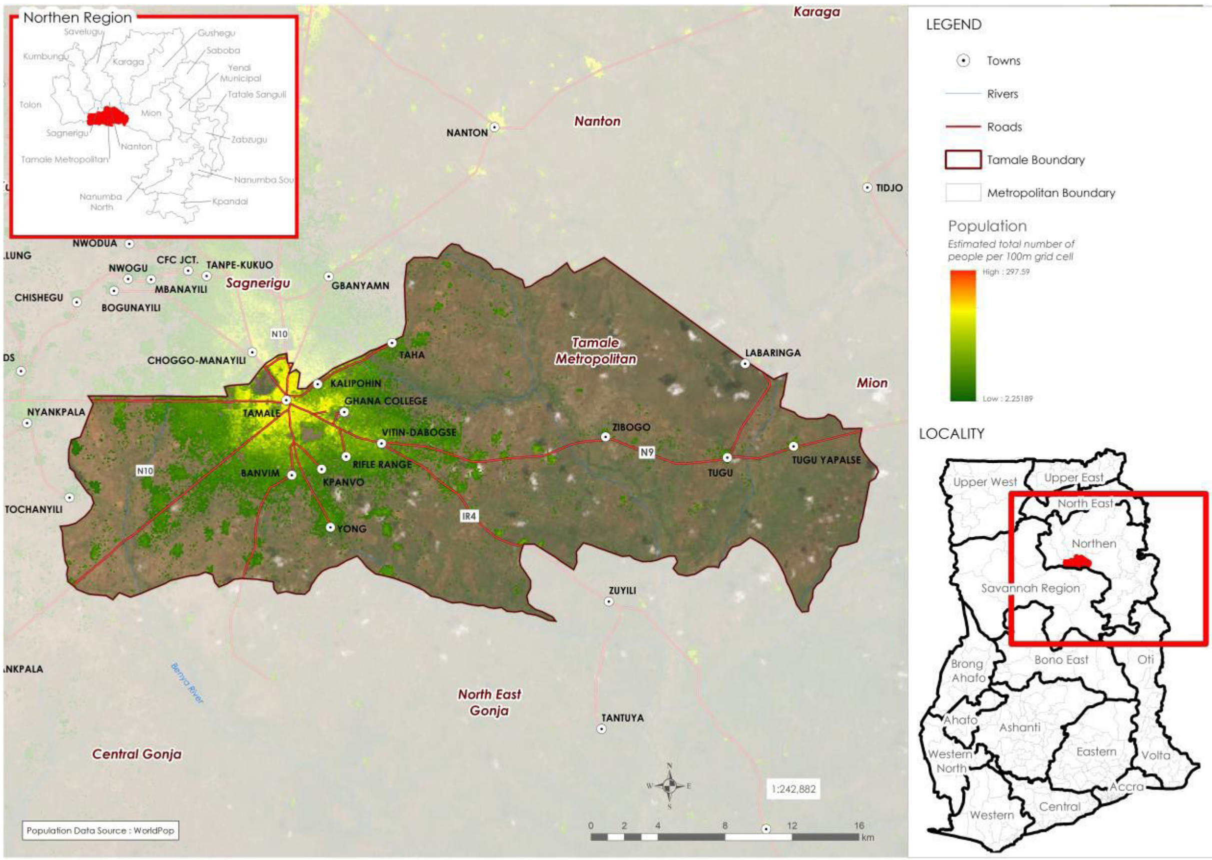
The results from the 2021 Census Report also show that the Metropole is the only district in the Region with 100% urban population, while in the previous census (2010), the urban proportion of the total population was 80.8% and the rural population was 19.2%. The latest Census Report also does not categorise how many people are living in peri-urban and informal areas, but it is thought that this is growing, and that these communities are particularly vulnerable to climate change impacts.

The Metropole has a diversity of ethnic and tribal groups. The Dagombas are the traditional occupants of this area (more than 80%), but several other tribal groups are now in the area, including the Gonja, Mamprusi, Nanumba, Konkomba, Asantes, Ewes, Hausa and some other minorities.

The Metropole has also steadily experienced migration and urbanization (Kosoe et al., 2022; Kuusaana & Eledi, 2015). Research suggests that migrants, in search of land, are encroaching on urban green spaces and water bodies which, in turn, is leading to a greater destruction impact from floods, and also limiting available land for farmers in the area (Kosoe et al., 2022; Kuusaana & Eledi, 2015).

Most of the population (60.1%), aged 11 and above, are literate. About 27.2% are literate only in English, 9.4% in a Ghanaian language only, and 61.8% are literate in both English and a Ghanaian language (GSS, 2014).

Figure C. 8 I Population distribution in TaMA, 2020



Source: (WorldPop Spatial Data Infrastructure, 2022)

C4 I Land Use and Spatial Planning

Rated as one of the fastest growing cities in West Africa, Tamale is a major urban, economic, financial, cultural and political centre (Abu & Peprah, 2020). Though the 2021

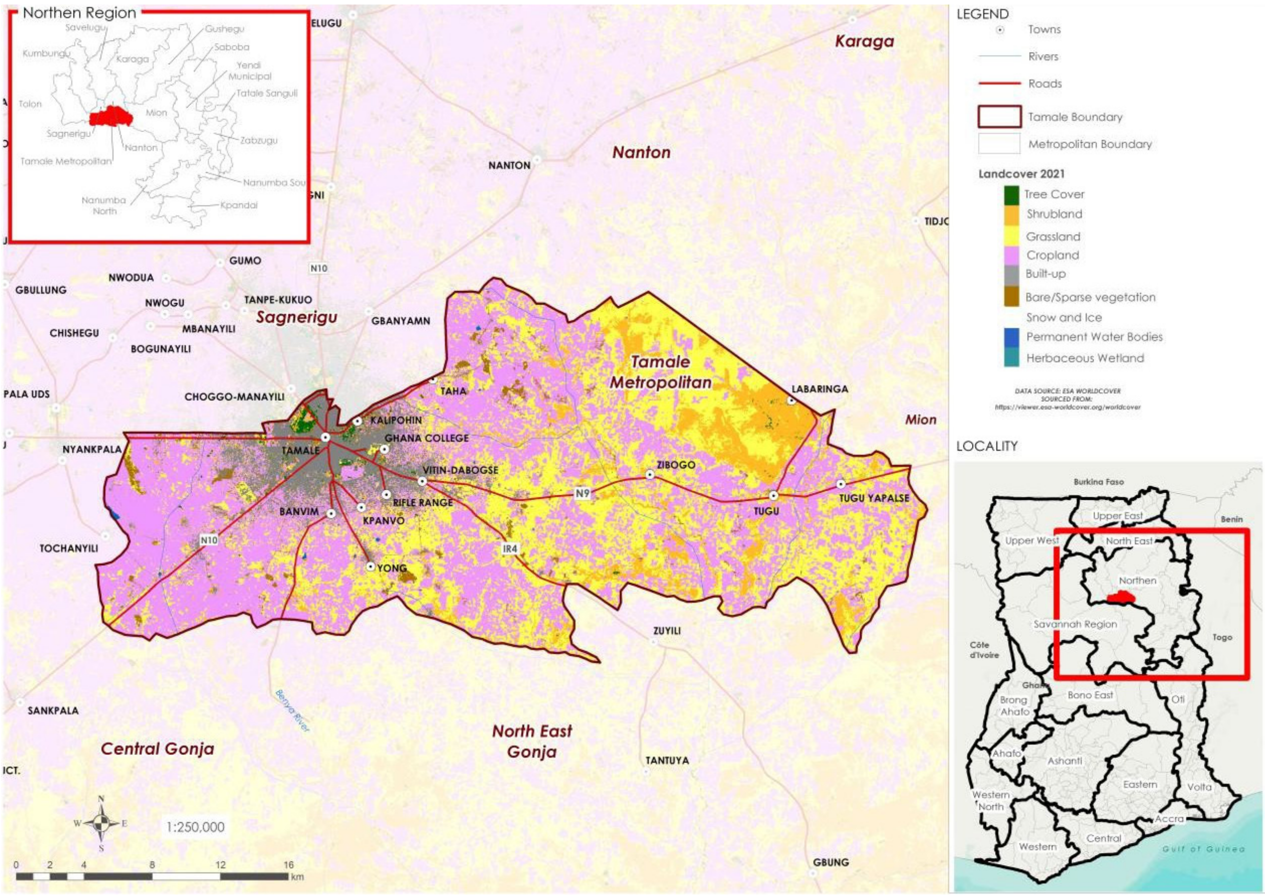
Census Report states that TaMA is 100% urban (GSS, 2021), the TaMA Composite Budget for 2020-2023, states that there are 117 communities in the Metropole, of which 41 (35%) are urban, 15 (13%) are peri- urban, and 61 (52%) are rural in nature (Tamale Metropolitan Assembly, 2020).

The rural parts of Tamale are the areas where land for agricultural activities is available, to a large extent, and the areas serve as the food basket for the Metropole. However, these communities still lack basic social and economic infrastructure such as good road networks, education facilities, hospitals, markets and recreational centres. The large, and potentially fastest growing proportion of peri-urban communities, is also a concern, as these are often areas that are particularly vulnerable to climate hazards.

Land allocation in Ghana follows a patrilineal system with regard to land inheritance. Accordingly, inheritances can go to a man's sons or brothers. Land allocation in traditional society tends to be acknowledged by communal recognition and observation, or that of the ruling traditional elder. Deeds or papers are not usually involved, nor are lawyers. The existence of deeds or papers usually indicates a previous dispute over the land, which was processed by the court system. When a conflict emerges, the traditional avenue for resolution is to have the traditional elder arbitrate. However, this process usually only works when both parties respect the traditional elder. If one or both parties lack confidence in the traditional elder, local politicians are frequently asked to arbitrate. Land disputes may be taken to the court system, but this is costly. In some areas, recourse to the courts is less likely because of the costs involved, and because of less confidence in, and acceptance of, that system as a dispute-settling mechanism. Nevertheless, even if a case goes before the courts, the land may still be used and/or occupied by the disputants, since it often is the source of livelihood of the disputants. Force may be used to settle cases where traditional authority involvement is ineffective.

There are no firm estimates as to the percentage of urban dwellers living in informal settlements in Tamale. However, among other cities in Ghana and the Northern Region, around 40% of the urban population reside in informal settlements. These individuals are mostly poor and working in informal jobs, if employed at all. Informal settlements are often underserved with regards to water and sanitation services, security, education and health services, which ultimately contributes to the high vulnerability of these populations. Additionally, settlements are often located in areas most vulnerable to flooding, and more exposed to heat and drought. This can result in less access to electricity and clean water. More broadly, throughout Africa, climate change is a growing threat to cities, especially the most vulnerable people, who are often forced to live in flood-prone areas, lack protective infrastructure, and reside in substandard housing. However, the linkages between climate change and rapid urbanization are not well-studied, and climate change is not well-integrated into urban planning (Kosoe et al. 2022). This can make informal settlements, such as those in Tamale, extremely vulnerable to climate hazards.

Figure C. 9 I Land use in TaMA, 2021



C5 I Economy and Employment

The economic sector with the highest employment levels in Tamale, is service and sales (33.0%), followed by those in the craft and related trades (21.5%). The proportion of the employed persons engaged in the agriculture, forestry and fisheries sectors, is 17.6%, and in manufacturing is 12.5%.

Wholesale, agriculture, and retail and manufacturing account for 64.1% of the industrial base.

According to the 2010 Census data the economically active population was 63.3%, of which 92.6% were employed and 7.4% were unemployed. The proportion of economically active men was 65.5%, of which 92.8% were employed and 7.2% unemployed. The proportion of economically active women was 61.1%, of which 92.3% were employed and 7.7% unemployed (GSS, 2014).

Agriculture is an important sector of Ghana's economy, employing about 60.0% of the economically active population of the nation in 2010 (GSS, 2010). This sector is critical to the national economy, contributing 21.3% to the Gross Domestic Product (GDP) in 2013 (MOFEP, 2013). The 2010 Population and Housing Census Report revealed that more than half (56.3%) of the population in the urban areas are engaged in agriculture, whereas less than half (43.3%) of the population in the rural areas are also engaged in agriculture.

The main types of farming activities considered in the 2010 population and housing Census in Ghana, are crop farming (excluding gardening), tree growing, livestock farming and fishing. Crop farming was the most dominant in the Metropole as a whole, accounting for more than half (52.9%) of the population in the urban areas, with less than half (43.3%) of the population farming cropsin the rural areas. Livestock farming accounted for 49.8% and 50.2% of urban and rural households, respectively.

Only 0.1% of households participated in fish farming in the TaMA, due to the lack of water bodies suitable for aquaculture development (GSS, 2014). However, recent research suggests that fish farming within the Metropole could play an important role in maintaining high levels of dietary nutrition (Akuffo & Quagrainie, 2019). In 2010, the proportion of the population practicing livestock farming in the rural and urban areas, was roughly equal, with approximately 50.2% and 49.8%, respectively. Livestock such as chickens, goats and sheep, are kept by many people, but in relatively small numbers. This perhaps explains the subsistence nature of farming in Tamale. Chickens are the kept in highest numbers (28 per owner), followed by cattle (26 per owner).

In recent years, the economy of Tamale has transitioned from agrarian, to being more services-based. The proportion of the population engaged in agriculture (crop farming and livestock farming) was around 70% until the early 1980s. In 2010, around 26% of the population was involved in agriculture (GSS, 2014). However, informal crop production is also practiced in backyard farming operations within the Metropole (Nchanji, 2017). This shift towards a more serviced-based economy was brought about by several factors, including the post-independence governments' support for agriculture through the introduction of input subsidies, a low level of industrialisation to generate non-farming related jobs, and the population's limited access to public-sector employment due to low levels of education (Songsore, 2009; Fuseini, 2014).

In the past, a vibrant rice industry impacted positively on the growth of Tamale. Songsore (2009) suggests that the collapse of the rice industry, following political instability in Ghana in the late 1970s and early 1980s, coupled with the poor economic performance and the subsequent introduction of the World Bank and International Monetary Fund sponsored Structural adjustment programs, affected the agricultural sector and its capacity to generate employment which contributed to its decline in Ghana (Fuseini, 2016).

Additionally, urbanisation pressures and associated environmental degradation have been reducing the number of shea trees in the TaMA, which are the anchor of women's livelihoods, either through the gathering and sale of the nuts, or agro-processing. This has resulted in a partial loss of their livelihoods, as much of the natural bush areas where they gather the nuts, has disappeared. It is suggested that, to address this loss of income, women be encouraged to engage more in nut processing and other agro-processing activities (e.g. rice, groundnuts) (Fuseini, 2016).

The rural parts of Tamale are the areas where land for agricultural activities is mostly available and that serve as the food basket for the Metropole. However, these communities still lack basic social and economic infrastructure such as good road networks, educational facilities, hospitals, markets, and recreational centres (Tamale Metropolitan Assembly, 2020)). This is limiting their potential for economic growth.

C6 I Livelihoods and Community

Housing and Living Environment

Tamale is noted for its male-dominated household roles, coupled with a low level, or lack, of assets controlled by women. Most of the housing in Tamale composes of compound houses constructed from mud and thatch. The housing stock of TaMA is 19,387, representing 7.5% of the number of

houses in the Northern Region. There are a total of 35,408 households, and the average household size is 6.3 persons, which is lower than the regional average.

There are four main types of dwelling units in Tamale. These are the separate, isolated houses (Self Contained), the semi-detached houses, separate room (s) within a compound usually with common cooking and toilet facilities, and several huts or buildings within a common compound (2020 Composite Budget - Tamale Metropolitan). Most of the population are living in the compound house structures where toilet, bath and kitchen structures are shared by two or more families. These are largely privately constructed for renting to the general population. The Metropole currently has a deficit in housing stock, which is mainly attributed to a backlog in government housing initiatives. Due to this backlog, individual private landlords take advantage and charge tenants very high rents .

There is a high demand for affordable housing units for the large population within the formal sector. The need therefore exists for government and private sector intervention in the provision of housing units.

Central government, and international bodies, are normally responsible for the preparation and implementation of informal housing upgrade projects within Ghana. Consequently, individual cities such as Tamale do not have their own strategies aimed at such upgrading. Individual cities should make a conscious effort to establish these guidelines and strategies. Other challenges for cities in Ghana such as Tamale, include services that have not been extended to all areas, low levels of service provision, where they do exist, non-conformity to development and building regulations, interspersed development of housing in new areas, the high cost of servicing such developments, and the aged housing stock[13].

Food Security

A study conducted by Abdul-Fatahi Alidu (2020) indicated that, of all the households in Tamale, 8.66% were severely food insecure, 36.67% were moderately food insecure, 40.67% were mildly

food insecure, and 14% were food secure. The results showed that location, income, household size, access to credit, education, assets, and household farm size, significantly influence the level of household food security. The study also showed that there is no significant relationship between gender and household food security status (Alidu, 2020).

However, women have disproportionately less control over agricultural land in the area, which can limit their ability to combat issues related to hunger and food security (Kapfudzaruwa et al., 2018).

The Metropolitan Department of Agriculture is a decentralized department under the TaMA. This department falls under the Ministry of Food and Agriculture (MoFA). The department is located at Vittin, in the Tamale South Sub-Metro, and the Vittin Town Council in general. This department is tasked with the responsibility of

13 Source: 2020 Composite Budget - Tamale Metropolitan.

ensuring food self-sufficiency and for the provision of services aimed at increasing agricultural productivity in the Tamale Metropolis. To achieve food self-sufficiency and increase productivity, the Department of Agriculture collaborates with several other governmental and non-governmental organizations, in particular the farming population in the Metropolis.

Poverty

Poverty is a huge concern among urban dwellers due to an average monthly income of only GHS150 and an exorbitant basket of expenditure. This is based on the level of expenditure of

urban dwellers, which is far more than the average income earned (Damba, Abarike, Nabilse, & & Akudugu, 2019). This is a concern, even among household heads, as remittances and other sources of income, are not forthcoming.

Urban poverty is enhanced by the lack of social capital, coupled with increasing utility tariffs with a translated cost in production and processing activities. The result is an increase in food prices and in the cost of utility tariffs (Damba, Abarike, Nabilse, & & Akudugu, 2019).

Urban dwellers consider unemployment as poverty, but still consider living in urban areas better than living in rural areas, due to the availability of basic amenities such as toilets, access to portable drinking water and electricity. Generally, control and access to resources, are associated with men. Thus, poverty and low income are associated with the sex of household heads and suggests that limited economic opportunity worsens the plight of women in the urban areas. This, therefore, calls for livelihood intervention programmes to address the unemployment situations of women (Damba, Abarike, Nabilse, & & Akudugu, 2019).

Migration

Tamale has attracted migrants from the impoverished rural areas of Northern Ghana, in particular, and has experienced annual urban growth rates of 4% during the past decade. This rapid urban

growth poses challenges for urban infrastructure and service provision, and has resulted in increased competition over land use, while effective planning to address present and future urban growth, is lacking. In Tamale, conflicts over the allocation and use of land between traditional authorities, responsible for managing 90% of the land, and governmental planning institutions, makes proper urban planning even more difficult (Karg, et al., 2019).

A survey of 120 migrants found that nearly 47% migrated with the purpose of seeking economic opportunities. Nearly a quarter reported experiencing language barriers, and 20% reported the high cost of living, as the main challenges faced (Yahaya 2021). They tend to settle in informal/ slum areas and take unskilled labour jobs (Yahaya, 2021).

Vulnerable Groups

Various documents and studies have highlighted that the most vulnerable groups within Ghana are women (elderly and orphans), children, people with disabilities, and low-income individuals and households in both a rural and urban setting. According to these studies, the main drivers of vulnerability are social and physical identities (gender, age, disability, ethnicity and refugee

status), income, poverty and political drivers (linkages to political networks and ethnic affiliations, and the key role of government). This is likely to be the case for the Tamale Metropolis.

Women, children, people with disabilities, people in remote or indigenous communities, and other vulnerable groups, are usually disproportionately affected by the loss of services when infrastructure systems fail, due to the impacts of climate change and environmental shocks. Often, it is these groups that bear the brunt of damages caused by natural disasters, as they may lack the resources to rebuild their homes, communities, and livelihoods, and may be disproportionately affected by health and other impacts caused by disruptions to basic services (Adshead, et al., 2022).

Further drivers for exclusions are income poverty, lack of local or political and/or wealthy connections, gendered social roles, lack of access to key public services (water, drainage, health facilities, electricity and schooling), location (rural and remote, or excluded neighbourhoods within an area), and social norms (Sarwar, Holmes, Korboe, Afram, & Salomon, 2022). Increasing migration into Ghana, and from rural to urban areas, is also increasing the number of vulnerable groups, particularly those who cannot access land and are forced to live in informal and peri-urban settlements, often located in high-risk areas.

C7 I Health

The health services in the Metropole are managed at three levels, namely: Metro Health Administration level, Sub-district level and the Community level. Health services are provided at the community level by sub-district staff, supported by traditional birth attendants, community-

based surveillance volunteers, and village health committees. Tamale Teaching Hospital is the main medical referral centre for Northern Ghana and provides services in multiple disciplines.

In TaMA, malaria, diarrhoea, and more recently COVID-19, are the most important causes of morbidity and mortality. Among children under five years of age, several environmental and behavioural risk factors were found to cause childhood diarrhoea. There is a significant association between childhood diarrhoea morbidity and toilet sharing ($p < 0.01$), depending on water from vendors ($p < 0.01$), storing water in containers ($p = 0.02$), and the frequent consumption of prepared foods from street vendors ($p = 0.04$) (Osumanu, 2007).

C8 I Infrastructure and Services

Transport

The roads in the Metropole are in fair condition, especially those that link the Metropole to other district capitals. The tarred roads in the area facilitate easy commuting from one area to the other And no traffic congestion is experienced. Most of the farming and peri-urban communities, are linked to the marketing centres by feeder roads. The availability of access roads linking farming communities is an incentive to the farmers, since post-harvest losses are reduced. Although most of the roads are tarred, some linking the regional capital to the remotest of areas, are yet to be tarred. Others have been gravelled, but are still to be tarred (Tamale Metropolitan Assembly, 2020).

Energy Supply

The Metropole is supplied with electricity from the national grid, the supply of which has been fairly stable, and about 70% of communities are connected. This could be advantageous to heavy industrial development, that would depend mostly on energy for production. With the expansion

of electricity in the Metropole, there is also an expansion of the small- and medium-cale enterprise businesses in the area (Tamale Metropolitan Assembly, 2020).

About 82.2% of households in the Metropole have access to electricity from the main grid. The proportion of households connected to the main grid in the urban areas is 90.5%, whilst 42.2% are connected in the rural areas. The three main sources of lighting for most households are electricity from the main grid, constituting 82.2% of households, kerosene lamp (11.6%) and flashlight/torch (4.7%). The sources of lighting for dwelling units in the Metropole include electricity, kerosene lamp, solar energy, firewood, and flashlight or torch. About 11.6% of dwelling units use kerosene as their main source of lighting. The proportion for the rural areas is 36.4%, whilst that of the urban areas is 6.4%. Access to electricity from the main grid is heavily skewed towards the urban areas. All other sources of lighting except flashlight/torch, account for less than 1.0% of dwelling units (Tamale Metropolitan Assembly, 2020).

Ghana's main sources of electrical power are hydro and thermal, mainly fuelled by natural gas, heavy fuel oil, light crude oil and diesel fuel oil. The primary source of electrical power used to be from hydropower, from the Akosombo, Kpong and Bui Generation Stations. However, the shift from hydro to thermal has helped Ghana to increase energy security. The share of hydro in the total electricity generation decreased from 92% in 2000, to 34.1% in 2021, whilst that of thermal increased from 8% in 2000, to 65.3% in 2021. Generation from renewable sources has been gradually increasing due to the continuous decline in the cost of photovoltaic (PV) and wind technologies, and a concerted effort to diversify the mix. The share of renewables in the generation mix in 2021 represents a doubling of its 2020 share of 0.28% (Energy Commission, 2022).

The Volta River Authority, a state-owned energy utility company, which is the main generator and supplier of electricity in Ghana, has been developing and implementing policies and programs, and introducing climate smart interventions in the operations of the Authority, to reduce Greenhouse Gas emission levels and to contribute towards pollution prevention, waste reduction and sustainable development. Interventions such as the Volta Gorge Reforestation Programme, Climate Smart Stove Initiative, and corporate initiatives such as the Corporate Waste Segregation Programme, as well as the use of less carbon-intensive fuels in generation activities, have been implemented. Furthermore, the Authority has, since 2018, operated all its thermal plants on natural gas, which has lead to a significant reduction in carbon emissions (Volta River Authority, 2023).

Water Supply and Sanitation

The Ghana Water Company Limited (GWCL) extracts raw water from the Nawuni abstraction point at approximately 35 km north-west of the City, and treats it at the Dalun Water Treatment Plant (WTP), for reticulation to the TaMA and the surrounding communities, where approximately 65%

of the population has access to the piped water supply network. However, water supply to the City of Tamale and surrounding areas is severely compromised by indiscriminate sand mining activities and land degradation in the catchment, which is causing sedimentation of the river, with noticeable physical changes in riverbed structure. Not only is the river becoming shallower and wider at the Nawuni abstraction point, but the quality of water has rapidly deteriorated, with turbidity becoming a major issue in the treatment of water for reticulation. In 2022 it was reported that the river was under serious threat from the illegal activities of sand mining, and the Ghana Water Company Limited (GWCL) has threatened to shut down the water treatment plant as a result. The depth of the river has been reduced due to siltation, which has undermined its water holding capacity and which increases the risk of flooding (Fugu, 2022).

The main water system in the Metropole is piped water, served by an aged reticulation network that does not reach all the urban communities in the TaMA, especially those located on elevated areas. Other sources of water are municipal water systems, mechanized bore holes, wells, dams and dugouts. (Tamale Metropolitan Assembly, 2020). Most households in the metropolis depend on either pipe-borne water outside their dwelling, or pipe-borne water inside their dwelling (representing 41.4% and 39.8% respectively). Rural communities, specifically the Dungu community, rely largely on small dams for drinking water (Alhassan & Kwakwa, 2014). However, inadequate access to safe drinking water in the area can force households to implement water purifying methods such as cloth filtration, and require women and children to devote their time to finding safe water sources (Alhassan & Kwakwa, 2014).

Groundwater is also an important water source for many people in the Northern Region of Ghana. According to the Census 2010, about 3.3% of households in Tamale use groundwater, particularly from boreholes (2%), protected wells (1%) and unprotected wells (0.3%). Most rural areas, and some urban dwellers, in Ghana, resort to groundwater (boreholes) for drinking, domestic purposes and for the irrigation of crops. An intermittent supply of piped water has created the need for inhabitants to also rely on wells, dams and dugouts for potable water, especially during the dry season in the Tamale Metropolis (Cobbina, Yakubu, Akpabey, Duwiejuah, & Naangmenyele, 2021).

Only around 56.2% of households in Tamale have access to a public or private toilet, while 7.1% of households have access to a twin-pit VIP latrine (KVIP). As much as 26.1% of households have no toilet facility. This is an area of concern in terms of the impact on the environment and the health of these communities.

The challenges for the provision of safe sanitation services in Tamale, and across Ghana, are linked to the inability to create proper disposal points for solid waste, to the lack of enforcement of sanitation laws, to population growth and to poor financing of sanitation policies, among others (Tamale Metropolitan Assembly, 2022).

Stormwater and Flood Risk Management

Urban flooding is a problem in Tamale due to a lack of adequate stormwater design and infrastructure and maintenance. The lack of stormwater drainage systems in informal settlements

has negative implications for human life and livelihoods due to flooding. The impact of flooding results in relocation, as well as the increased potential for waterborne diseases. Flooding has also resulted in damage to electricity and health infrastructure in Tamale (Gough et al., 2019). Case study interviews with health personnel in Tamale and Accra indicated that flooding events during the rainy season were associated with an increase in malaria and cholera cases. Additionally, flooding resulted in physical damage to health care facilities and to essential medical equipment and medication. Flooding events were also reported to damage electricity infrastructure and result in interruptions to electricity supply in the cities (Gough et al., 2019). Changes in rainfall and temperature, and the increase in the occurrence of short-term flood events, will have a negative impact on human settlements in particular.

The impact of flooding on human settlements may be temporary and relatively short-term,– albeit costly, in nature (for example, physical damage to infrastructure such as buildings, pipelines, roads, substations and railway lines), or might have lasting repercussions, such as loss of life, disruptions to livelihoods, physical isolation and relocation.

Solid Waste Management

The most widely used method of solid waste disposal in the TaMA is by public dump (container), accounting for 98.3% households within the Tamale Metropolis. About 72.5% of households have

their solid waste collected, with the remaining households resorting to indiscriminate dumping. The inability to create proper disposal points for solid waste is considered a major challenge in Tamale and is also contributing to the sanitation and flooding risks, and impacting on the health and well-being of people. This a major challenge for all African cities.

While Tamale lacks a formal recycling program, incentive-based waste recovery schemes have shown to be beneficial in encouraging recovery of dry recyclables and food waste (Asare et al., 2020).

C9 I Future Growth and Development Planning

The Composite Annual Action Plan 2022 document outlines the development goals and strategies of TaMA for the year 2022. The Metropole identifies inadequate infrastructure as a key development issue. To address this, the assembly plans to construct new roads and to rehabilitate existing ones, to construct drains and culverts, and to install streetlights.

In terms of economic growth and development, TaMA seeks to support the growth of the agricultural sector, to promote investment, and to improve the business environment to facilitate trade and economic development. These include the establishment of an agro-processing centre, the development of a modern abattoir, and the creation of an investment promotion unit.

To promote trade and investment, TaMA plans to develop a new market complex and to establish an investment promotion unit. To address the issue of low revenue generation, there are plans to improve property rates collection by intensifying property rates enforcement and by implementing an electronic property rates billing system. In terms of local governance and participation, TaMA aims at improving citizen participation and promoting transparency and accountability. These include the establishment of community information centres and the conduct of regular town hall meetings.

Appendix D I Risk Assessment Methodology

D1 I Determining the Magnitude of the Hazard

Table D. 1 present the criteria to define the magnitude of the hazard.

Table D. 1 I Criteria for determining the magnitude of the hazard

Exposure	Description
Very Low	The hazard is expected to have minimal impact and unlikely to cause significant disruptions.
Low	The hazard is expected to have a low impact and may cause some minor disruptions or inconvenience, and yet can be easily managed.
Medium	The hazard is expected to have a moderate impact and may cause significant disruptions or inconvenience but can be managed with adequate preparation and response.
High	The hazard is expected to have a high impact and may cause widespread disruptions or significant harm, requiring a significant effort to manage.
Very High	The hazard is expected to have a very high impact and may cause catastrophic damage or widespread harm, requiring an immediate and large-scale response.

D2 I Determining the Level of Exposure

Table D. 2 present the criteria to determine the level of exposure.

Table D. 2 I Criteria for assessing the level of exposure

Exposure	Description
Very Low	In the past, the study area, or areas nearby, have rarely experienced extreme weather events (less than one event every 50 years).
Low	Exposure is almost unlikely. In the past, the study area, or areas nearby, have sporadically experienced extreme weather events (1 every 20-50 years).
Medium	Exposure is possible to occur. In the past, the study area, or areas nearby, have experienced extreme weather events (1 every 10-20 years).
High	Exposure is likely to occur. The study area, or areas nearby, have regularly experienced extreme weather events (1 every 5-10 years).
Very High	The exposure is almost certain. Hazard manifestation is common (1 every 1-5 years).

D3 I Assessing the Systems' Vulnerability

Table D. 3, and Table D. 4 present the criteria to assess sensitivity and adaptive capacity respectively. Table D. 5 presents the matrix used to assess and categorise the level of vulnerability for each system or asset.

Table D. 3 I Criteria to access sensitivity

Sensitivity	Description
Very Low	Extreme weather events and climate change related hazards may marginally affect the study area and there are no assets critically affected.
Low	Extreme weather events (strong winds, floods, extreme temperatures, droughts, sea level rise, coastal erosion etc.) relatively more resistant population, the consequence is classified as minor.
Medium	Extreme weather events cause moderate damage to local goods and services (e.g., increased incidences of dengue, diarrhoea, malaria or other vector -borne diseases affect the health of the local community and put greater pressure on sanitation and agricultural goods; or a moderate drought may lead to some loss of household income, but may not require external assistance).
High	Extreme weather events affect assets, reducing the capacity of local services to respond, causing damage to local communities (e.g., floods that lead to the interruption of water supply affecting communities and irrigation pump failures, reducing the productivity of agricultural productions, can have a major impact on a weak local community that has no other alternatives and cannot withstand seasonal shocks of this type).
Very High	Extreme weather events lead to the failure or destruction of local goods and services, communities must be relocated for at least several months, etc. This is a very high potential impact that could seriously affect local communities and the consequence is considered to be catastrophic.

Table D. 4 I Criteria to access adaptive capacity

Adaptive capacity	Description
Very high	Existence of good knowledge, institutions that function efficiently and sufficient means and technologies to avoid or reduce the exposure and/or sensitivity of the identified climate risks. Local communities have a good understanding of climate change and its effects/impacts and adopt initiatives to increase their resilience in the short, medium and long term. Existence of action strategies for climate change at the study area level.
High	Existence of alternative resources and capacities to diversify the local economy. Local populations have access to resilient infrastructure (built and natural/ecosystem services) that support means of production and livelihoods. Existence of technical capacity, strategies, a risk and disaster prevention plan, an action plan for climate change, etc.
Medium	Existence of a national/regional action plan for climate change etc., but no local climate action plan, including the participation of local communities. There is a moderate capacity to reduce sensitivity to identified climate risks and some adaptation measures are implemented at the community level to mitigate risks in the short and medium term. Existence of basic energy services, water supply to communities, etc. to address the potential impacts resulting from climate change.
Low	Lack of a legal, institutional and operational framework at the local level to mitigate climate risks and their effects on local ecosystems and livelihoods. Restricted access to resilient infrastructure (built and natural/ecosystem services) that support means of production and livelihood against the effects of variability and climate change.
Very Low	Lack of basic energy services, water supply to communities, etc. to address the potential impacts of climate change. Lack of knowledge and perception about the phenomenon of climate change and its effects on natural ecosystems and local livelihoods. Very limited and vulnerable means of survival and no alternative means.

Table D. 5 I Vulnerability Matrix

Vulnerability		Sensitivity				
		Very Low	Low	Medium	High	Very High
Adaptive capacity	Very High	Low	Low	Low	Medium	Medium
	High	Low	Low	Medium	Medium	High
	Medium	Low	Medium	Medium	High	High
	Very Low	Medium	Medium	High	High	Extreme
	Low	Medium	High	High	Extreme	Extreme

D4 I Evaluating Priority Risks

Table D. 6 presents the matrix used to rank the potential risks of the hazards associated with climate change on natural and human systems, based on exposure to identified climate hazards and the vulnerability of key natural systems, socioeconomic sectors and local livelihoods.

Table D. 6 I Risk Matrix

Risk		Hazard x Exposure			
		Low	Medium	High	Extreme
Vulnerability	Low	Low	Low	Medium	High
	Medium	Low	Medium	High	High
	High	Medium	High	High	Extreme
	Extreme	High	High	Extreme	Extreme