Adapting Together, Thriving Tomorrow

NATIONAL ADAPTATION PLAN GHANA

Climate Change Risk Assessment for Sekondi-Takoradi Metropolitan Assembly

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

FREEDOM AND JUSTICE

Sekondi-Takoradi Metropolitan Assembly

epa

UN environment programme

GREEN CLIMATE FUND

Contacts Information

No. 91 Starlet Street, Opp
Telephone: 050 6694760 /
050 6699466

P.O. Box M.326

info@epa.gov.gh

www.epa.gov.gh

Document Information

Title: Climate Change Risk Assessment for Sekondi-Takoradi Metropolitan Assembly: Enhancing Multi-Sector Planning and Capacity for Effective Adaptation in Ghana

Prepared for: Government of Ghana with support from GCF and UNEP

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
CORDEX	Coordinated Regional Downscaling Experiment
CRIDF	Climate Resilient Infrastructure Development Facility
CMIP	Climate Model Intercomparison Project
EPA	Environmental Protection Agency
GCF	Green Climate Fund
GHG	Greenhouse Gas
GIS	Geographic Information System
GMet	Ghana Meteorological Agency
GSS	Ghana Statistical Service
I&APs	Interested and Affected Parties
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
LE	Lower Extreme
MESTI	Ministry of Environment, Science, Technology and Innovation
MMDAs	Metropolitan, Municipal and District Assemblies
NAP	National Adaptation Plan
NDC	Nationally Determined Contributions
RCP	Representative Concentration Pathways
SOM	Self-Organising Map
SPEI	Standardised Precipitation and Evapotranspiration Index
SSP	Shared Socioeconomic Pathways
STMA	Sekondi-Takoradi Metropolitan Assembly
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
UE	Upper Extreme
WACA	West Africa Coastal Areas Management Programme
WGII	Working Group II of the IPCC

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 Coordinator.

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 wider 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 Study are as follows:

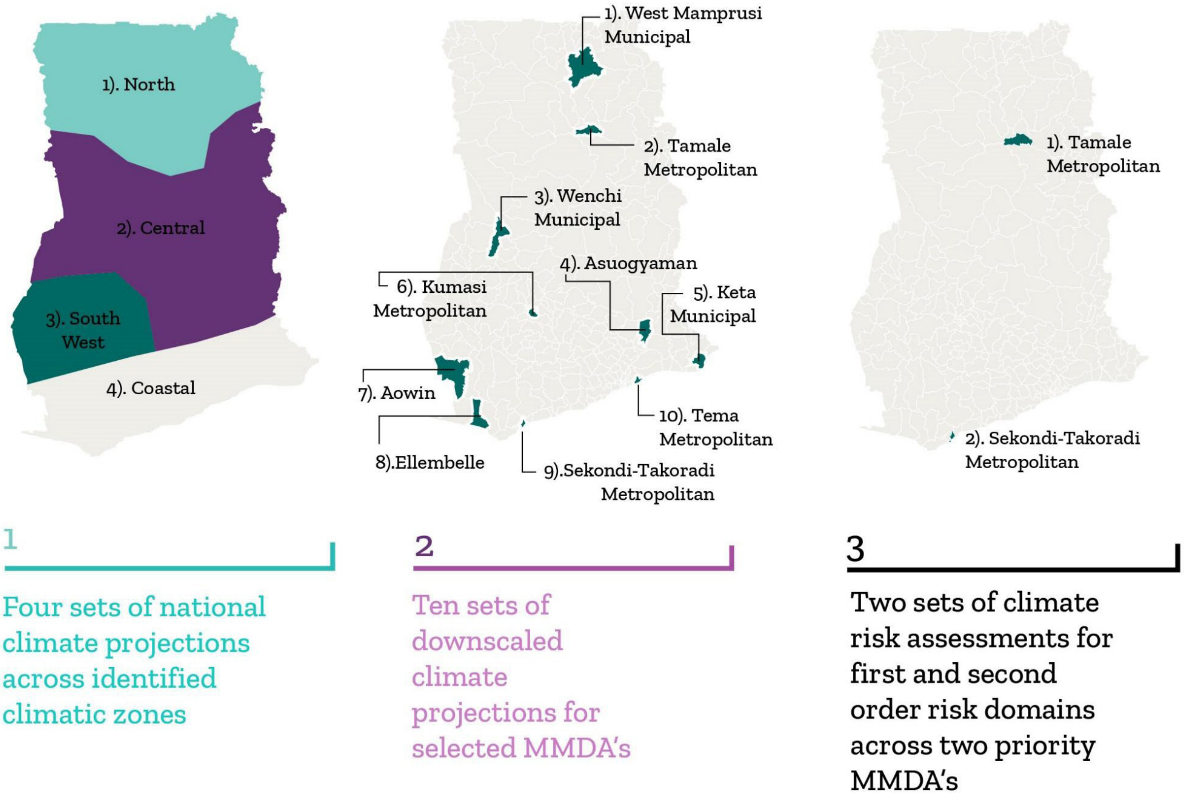
- Task 1: Develop a methodology for producing national climate change scenarios
- Task 2: Develop downscaled/area-based climate change projections for Ghana
- Task 3 & 4: Develop national and sub-national level climate risk assessments for two MMDAs
- Task 5: Summary for Policy Makers, Training and Capacity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

The identification of priority MMDAs followed a selection process developed in consultation with representatives of the Government of Ghana and with technical support from the UNEP (Figure 1).

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

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

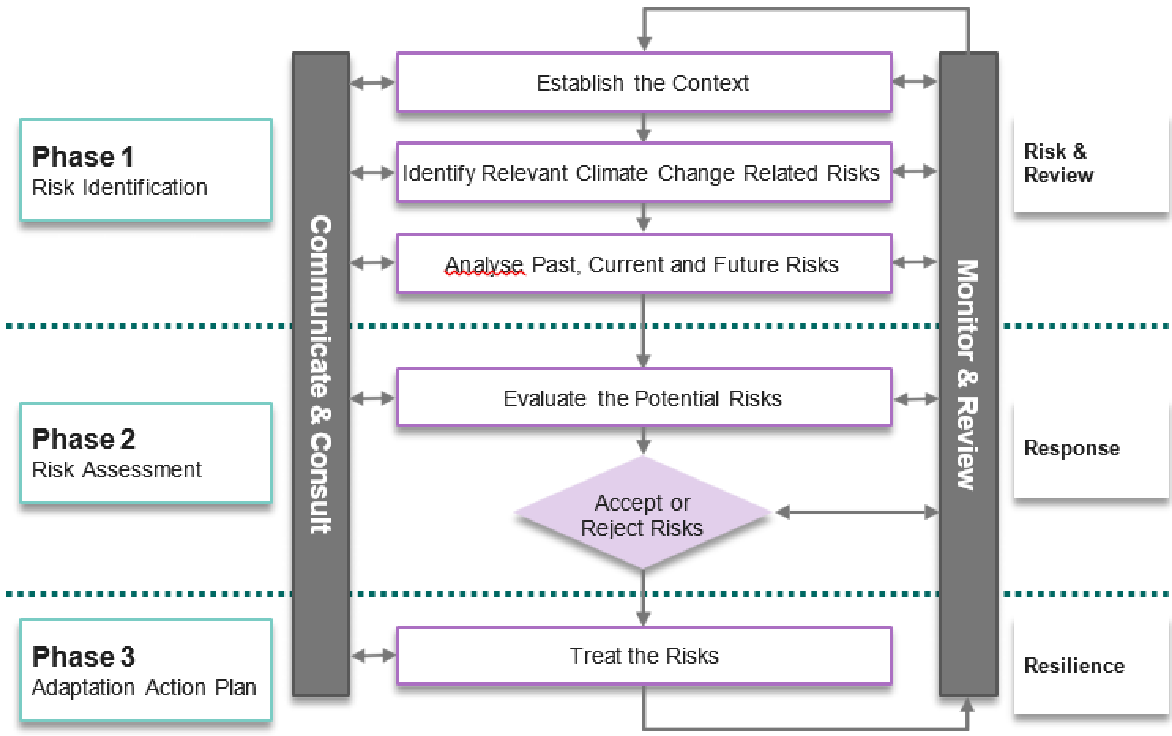
Figure 1 I Spatial scale of key deliverables



2 Approach and Methodology

The approach undertaking in determine the Climate Change Risk Assessment for Sekondi-Takoradi Metropolitan Assembly (STMA) follows the general risk assessment process as shown in Figure 2.

Figure 2 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 combination of a 'top down" and "bottom up" approach to evaluating climate change related risks.

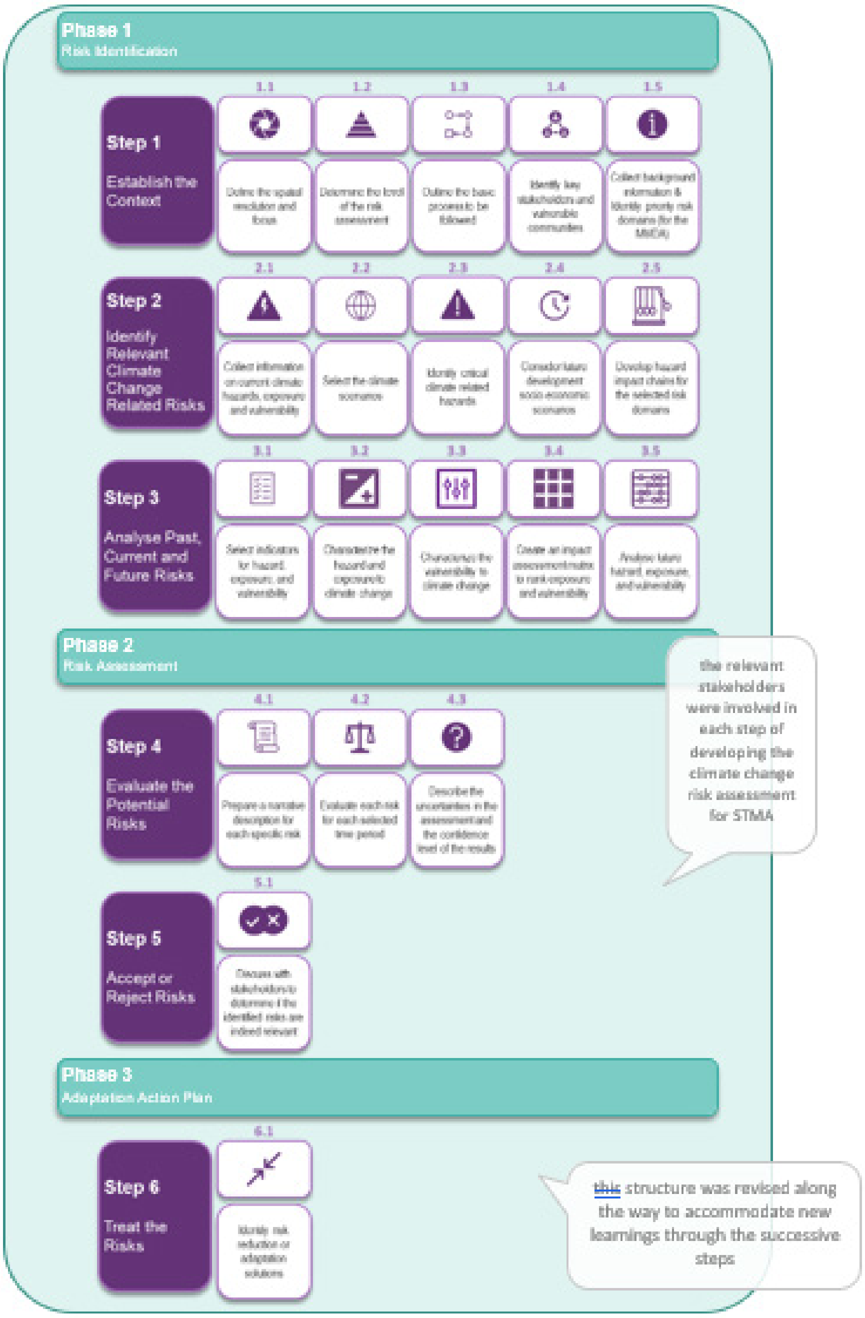
Climate change risk assessment should be a participatory process, sensitive to issues of gender, youth, and the possible presence of vulnerable groups. To this end, the involvement and commitment in the assessment process of interested and affected parties (I&APs), including members of local communities,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

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, the project team undertook a site mission from 28 November to 9 December 2022. The purpose of this trip was to engage stakeholders, to collect data and anecdotal evidence to understand better the current and potential future climate change related risks, their impacts and the adaptive capacity of local communities and institutions.

The basic approach to identifying the climate risk involved selecting the relevant key risk domains and then determining the relevant climate hazards and level of exposure and sensitivity and the potential for adaptive capacity pertinent to that specific risk domain or sub-sector.

Figure 3 summarises the specific steps, and timeline, followed for undertaking the CCRA.

Figure 3 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[1] 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 the following, and is shown graphically in Figure 4 (from IPCC, 2014):

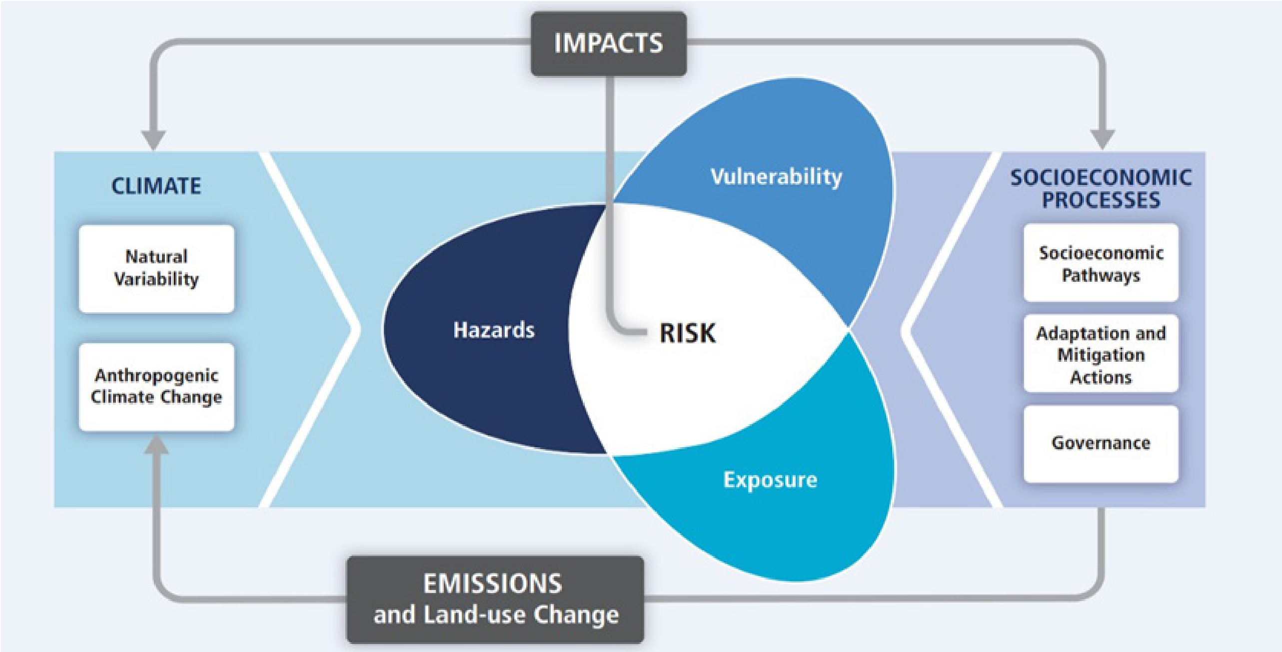
Climate Change Risk is defined as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses 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 **socio-economic 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/)

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

Figure 4 I Risk assessment framework for evaluating climate change risks (IPCC, 2015)



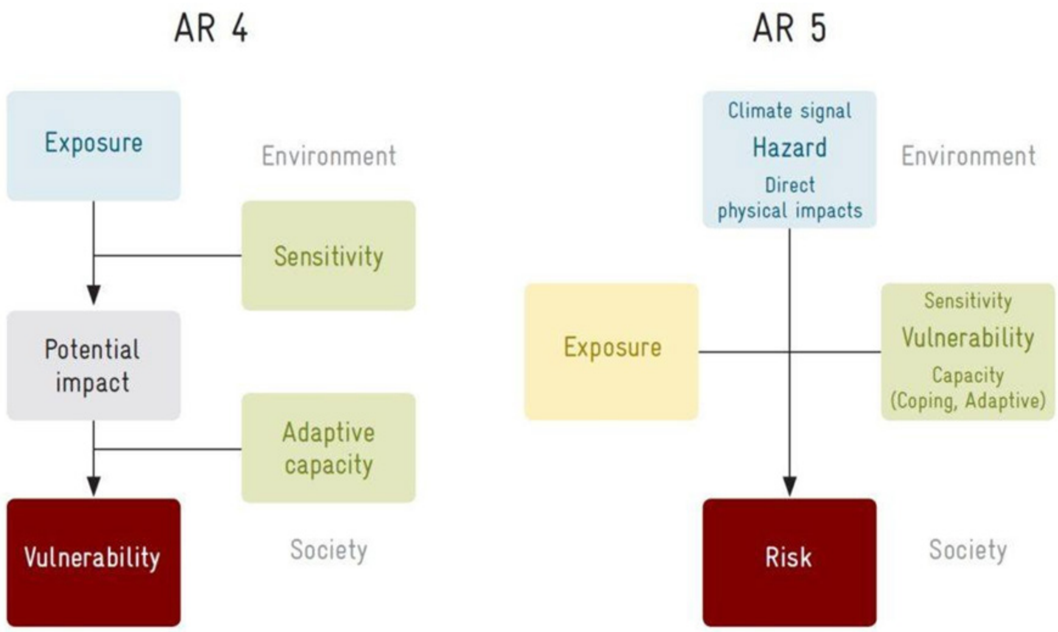
Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes including adaptation and mitigation (right)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

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

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., agriculture 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 5.

Figure 5 I Change in the conceptual approach to climate change risk and vulnerability assessments



Source: (Zebisch, et al., 2021)

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/)

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 coordination 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 on putting in place suitable policy conditions to enable the country to increase its efforts on 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
- Ghana's National Adaptation Plan Framework published in 2018, to provide an overall framework to guide the country in developing, coordinating, and implementing its NAP process.
- Fourth National Communication for the UNFCCC published in 2020
- Nationally Determined Contributions (NDC) (2020-2030) – updated in 2021

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 EPA, on behalf of the MESTI, seeks to provide the country to address medium to long-term adaptation planning gap.

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 and to advance low emission and climate resilient development (The World Bank Group, 2021a).

This CCRA for STMA 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 the data was downscaled at the STMA level where possible:

- CIG Ghana: Flood risk mapping and modelling report, 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), 2019Ghana 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.

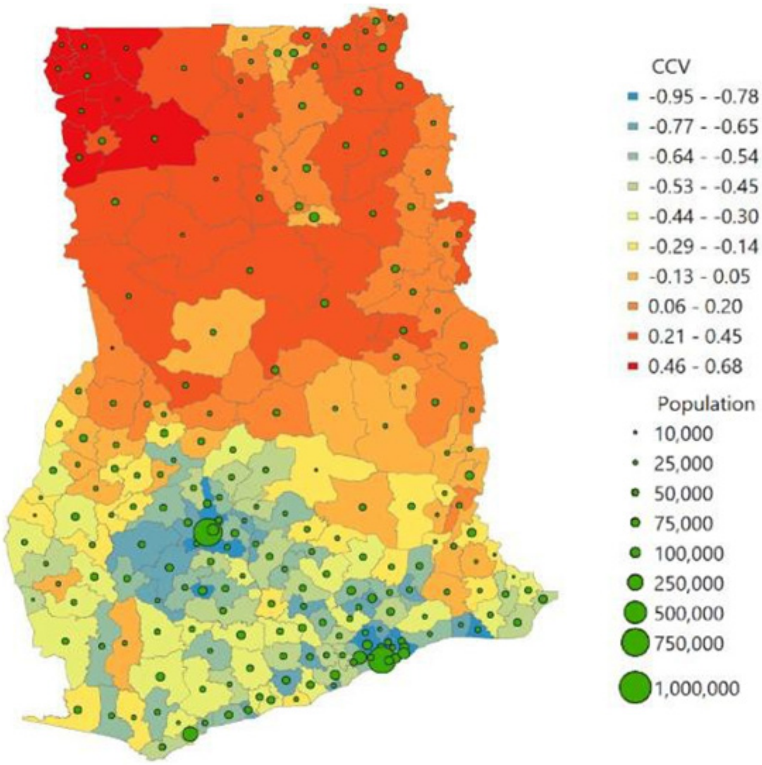
For this analysis exposure to climate change risk was determined based on the relative change in temperature and precipitation derived from an ensemble of 10 general circulation models downscaled using five regional climate models and for four sub-parameters including percentage change by: i) 2060 under RCP2.6; ii) 2060 under RCP 8.5; iii) 2080 under RCP 2.6; and iv) 2080 under RCP 8.5.

Sensitivity was determine based on the population employed in the agriculture 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 agriculture sector.

The final derived CCV for each district as well as the total population is shown in Figure 6.

Figure 6 l Climate change vulnerability scores for Ghana's 216 districts



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

The results from the CCV assessment revealed that the vulnerability of Ghana's districts generally increases from the coast into the transition zone and the northern savannas, and that Sekondi-Takoradi is ranked number **122** (out of 216 districts) in terms of climate change vulnerability although this does not necessarily reflect the expected impacts and risk associated with sea level rise.

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*[2].

Table 1 I Summary of critical climate related hazards for STMA from ThinkHazard! Tool

Hazard	River flood	Urban Flood	Coastal Flood	Earthquake	Landslide	Tsunami	Volcano	Cyclones	Water Scarcity	Extreme Heat	Wildfire
STMA	Low	Low	Medium	Very Low	Very low	Low	N/A	N/A	Medium	Medium	Medium

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

Table 1 shows that STMA has the following critical climate risks:

- **coastal flood hazard** is classified as medium. This means that there is more than a 20% chance of potentially damaging coastal flood waves occurring in the next 10 years.
- **water scarcity** is classified as medium. This means that there is up to 20% chance droughts will occur in the coming 10 years. Regarding the climate change impacts, model projections are inconsistent in their estimates of change in drought hazard, which influences water scarcity. The present hazard level may increase in the future because of climate change. It would be prudent to consider increased drought hazard and water scarcity in the long-term.
- **extreme heat hazard** is classified as medium. This means that there is more than a 25% chance that at least one period of prolonged exposure to extreme heat, resulting in heat stress, will occur in the next five years. According to the IPCC, continued emissions of greenhouse gases will cause further warming, and it is virtually certain that there will be more frequent hot temperature extremes over most land areas during the next fifty years. Warming will not be uniform. In this area, temperature increase will be slightly lower than the worldwide average, but still significant.
- **wildfire hazard** is classified as medium. This means that there is between a 10% and 50% chance of experiencing weather that could support a hazardous wildfire that may poses some risk of life and property loss in any given year. In areas already affected by wildfire, the fire season is likely to increase in duration, and include a greater number of days with weather that could support wildfires because of longer periods without rain. Climate projections indicate that there could also be an increase in the severity of wildfires. Areas of currently very low or low wildfire hazard could also potentially see an increase in the likelihood of wildfires, as climate projections indicate an expansion of the wildfire hazard zone as a result of hotter and dryer conditions.

It is important to note that river, urban and coastal flooding were not considered high risk and yet, there is anecdotal evidence that an increase in urban flooding is a major area of concern for Sekondi-Takoradi and

2 https://thinkhazard.org/en/

most cities in Ghana as a result of climate change. This has almost become an annual event as a result of excessive rainfalls causing the rivers to overflow their banks (Danso & Addo, 2017). Coastal floods are not a major issue yet, although there are flooding problems caused by coastal erosion. The potential for increase in coastal storms/storm surges and sea level rise, combined with urbanisation could potentially increase the risk and worsen the potential impacts of urban and coastal flooding (Triple Line Consulting Limited, 2022). The assessment that flooding risk is low, is likely because Thinkhazard! 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 considerations the underlying vulnerability of each location.

For this reason, it is important to undertake more detailed local level climate risk assessment.

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 interested and affected parties (I&APs), including members of local communities, should be integrated throughout the risk assessment process.

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. For this level of study stakeholder engagement was limited to a workshop of selected key local stakeholders, and validation by national level departments.

In order to inform the development of the climate risk assessment for Sekondi-Takoradi Metro the project team undertook a site mission from 28 November until 9 December. The purpose of this trip was to engage key stakeholders in STMA and at a national level with the purpose of:

a. Introducing the NAP (National Adaptation Plan) project and process.

b. Provide stakeholders with an overview of climate change, the potential impacts and various aspects that will be evaluated in the climate change risk assessment.

c. Present the outcomes of the down-scaled temperature and precipitation scenarios.

d. Validate the findings of the climate change projections.

e. To identify critical climate related risks and collect data and anecdotal evidence to better understand these risks, their impacts, and adaptive capacity of local communities.

The stakeholder engagement sessions in STMA (Figure 7) were coordinated through the local EPA offices. Two separate stakeholder engagement sessions were held on 1st December 2022, namely:

- A morning session included various departments of the Assembly. A total of 21 participants were present (excluding the project team).
- An afternoon session was held on the same day with non-assembly stakeholders including CSOs and private sector. In total 11 participants (excluding the project team) were present.

Figure 7 I Stakeholder engagement sessions in Sekondi-Takoradi Assembly

Following the engagement with local stakeholders in Sekondi-Takoradi, a second two-day workshop was held in Accra with national level stakeholders and government representative with the purpose of:

a. Presenting the outcomes of the down-scaled temperature and precipitation scenarios, including the evidence and data provided by the MMDA's on the priority risk domains.

b. Capture additional information on the critical climate related risks and adaptive capacity.

c. Provide training on the approach to undertaking a local level climate risk assessment.

Using the climate projections and other studies relating to the potential impact of climate change on the critical risk domains in Sekondi-Takoradi, 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. The process followed and the results of the assessment for Sekondi-Takoradi are presented in later sections. The list of the workshop participants is included in **Appendix B.**

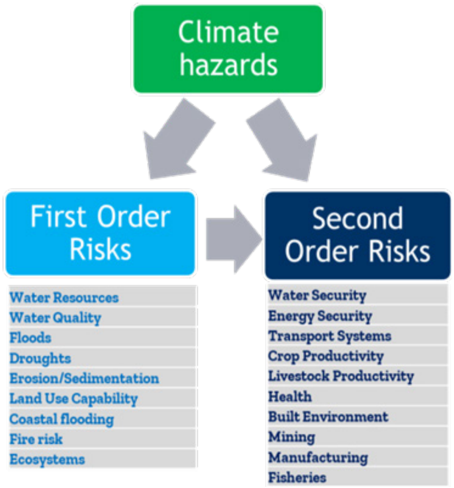
3.6 Identification of Priority Risk Domains and Critical Assets

To determine the specific priority risk domains considered for each of the MMDAs, it is 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 8.

Figure 8 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 STMA was developed based on a desk top 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 priority 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 STMA

Second order risk domains	First order risk domains
An important economic sector is the **fisheries industry**, and this has already been highlighted as an area of concern due to possible climate change risks. A component of this is also the potential impact on **transport systems** (i.e., roads and ports), mainly due to sea-level rise, as well as the overall impact on the **built environment**, particularly for cities like Accra.	Critical first order risk domains that support fisheries, transport and the built environment include **coastal flooding** and **inland flooding**, and in particularly areas where they overlap. **Upland and coastal ecosystems** are important in terms of ecosystem-based adaptation**.** It has been noted that there are several important **cultural sites** located on the coast near to Sekondi-Takoradi that could be impacted by **sea level rise** and increased **coastal flooding.**
Energy security could be considered as a second order risk domain, given the dependency on hydropower as well as reliable **water supply.**	**Water resources (availability)** is an important first order risk domain that should be considered.

Table 3 I Identified priority first and second order risk domains selected for Sekondi-Takoradi MA

First Order Risk Domain	Second Order Risk Domain
Water Resources (Groundwater)	Energy Security (e.g., thermal)
Erosion and Sedimentation	Transport Systems
Coastal Flooding	Fisheries
Ecosystems	

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 STMA.

- Fishery Industries
- Water Supply
- Critical infrastructure
- Agriculture
- Health systems
- Coastal Ecosystems

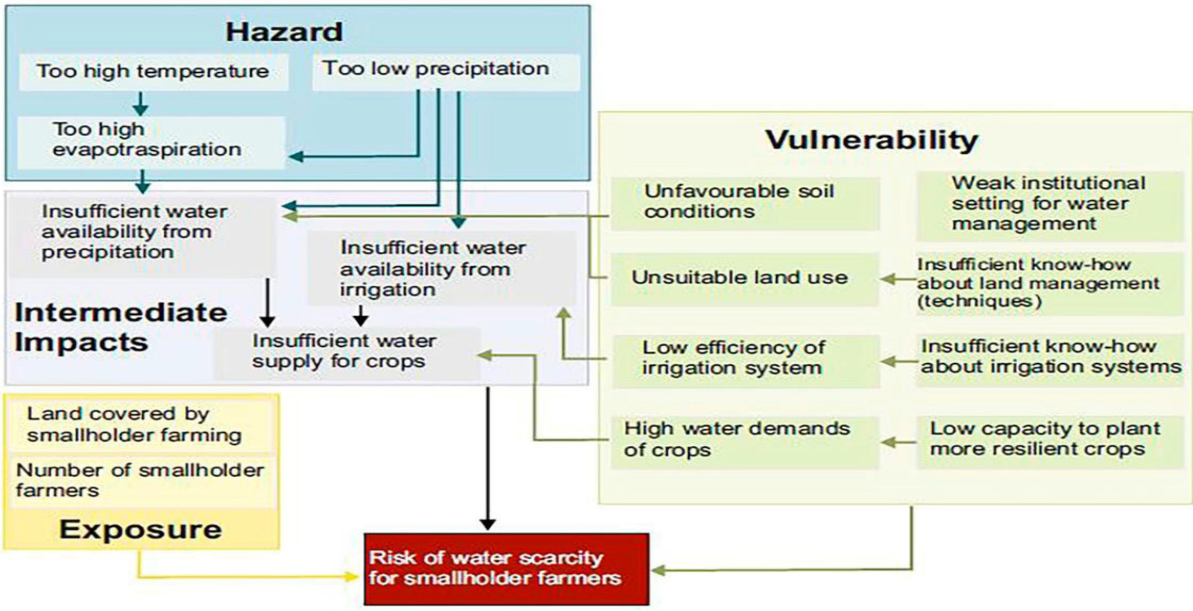
The related climate hazards and individual impact chains developed to inform the climate risk assessment for these priority systems and assets are presented in Section 6.

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 danger that cause it, the exposure that may be affected, and the vulnerability that relates the level of damage on the exposure to the magnitude of the risk are identified and represented.

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 of small holder farmers is shown below in Figure 9.

Figure 9 | Example impact chain for water scarcity risk for small holder farmers



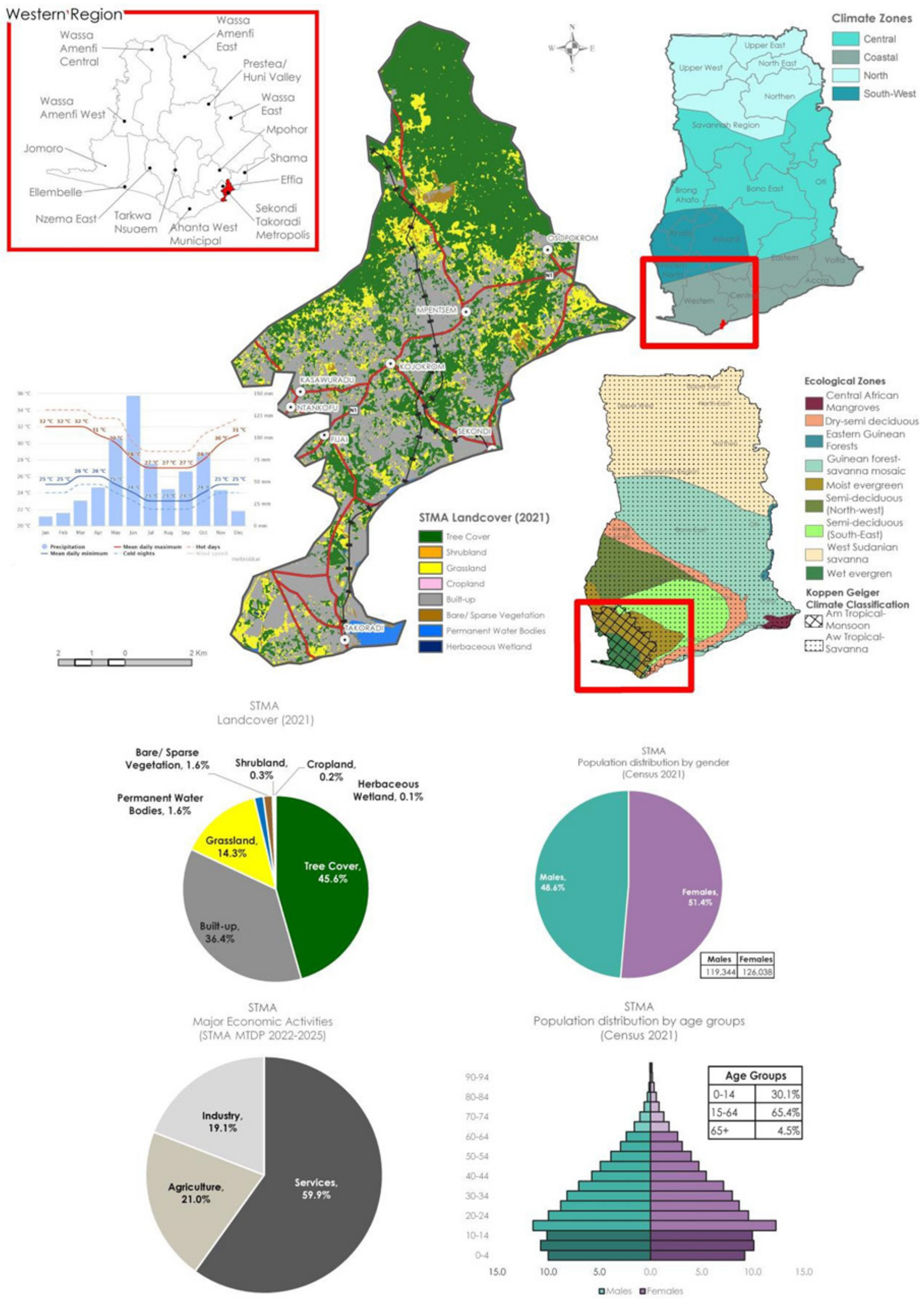
Source: (Menk, et al., 2022)

An example of a generic climate hazard impact chain for key risks in Ghana is shown in **Appendix A,** which 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, however this will need to be adapted for use in each specific MMDA based on the identified priority hazards and risk domains.

4

Overview of Sekondi-Takoradi Metropolitan Assembly

Figure 10 I Sekondi-Takoradi Metropolitan Assembly overview



Sekondi-Takoradi Metropolitan Assembly (STMA) is the administrative capital of the Western Region of Ghana, and includes three districts: Sekondi, Takoradi and Essikado Ketan (Figure 10). The STMA has a total land size of approximately 65 km^2. It is bordered to the north by Mpohor District, Shama District to the east, Effia-Kwesimintsim Municipal to the west and south by the Gulf of Guinea (Sekondi Takoradi Metropolitan Assembly, 2022).

The central area of STMA has an altitude of only 6 m above sea level which is very low lying and at risk from coastal flooding. The general low-lying nature of the topography especially in the coastal areas is a key challenge as heavy rains results in frequent flooding and increase the pressure on stormwater drainage and critical infrastructure (STMA Metro Planning and Coordinating Unit, 2021).

STMA is located in the Coastal Climate Zone as shown in Figure 10. The 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 based on 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 what to future climate change under the different global emission scenarios.

The daily temperature in the STMA typically varies from 23°C to 31°C and is rarely below 22°C or above 33°C. The hottest month of the year is March, with an average high of 31°C and low of 26°C. The coldest month of the year in is August, with an average low of 23°C and high of 27°C.

The mean annual rainfall is about 1 380 mm with an average of 122 rainy days per year, with the most precipitation occurring in June with 25.1 days and an average of 333 mm of precipitation, and the least precipitation occurring in January with 5.5 days and an average of 25.4 mm. During most months of the year, there is significant rainfall and there is only a short dry season, which is hot and partly cloudy. The wet season (May to October) is warm and mostly cloudy, and it is humid year-round. The climate diagram for the average temperature and precipitation for Sekondi-Takoradi, shown in Figure 10, is based on 30 years of hourly weather model simulations (Source: Meteoblue.com).

According to the 2021 Ghana Population and Housing Census, STMA has a total population of 245 382, comprising 119 344 (48.6%) males and 126 038 (51.4%) females, and a population density of approximately 3800 habitants/km^2. This represents 11.9% and 0.8% of the regional and national population respectively (Ghana Statistical Services, 2021). In 2010 the total population of the three STMA's sub-metros was 326,931, indicating that the population from STMA has declined by 81 549 over the past 11 years. This represents an average population growth rate of - 2.27% per year.

The latest revision of the population estimates and projections from the UN World Urbanization Prospects[3] estimates Sekondi-Takoradi's 2023 population at 1 077 929. In 2022, the population for the same area was 1 034 917, meaning a population increase of 43,012 people in the last year, representing a 4.16% increase. However, these estimates represent the urban agglomeration of Sekondi-Takoradi and its adjacent suburban areas (World Population Review, 2023).

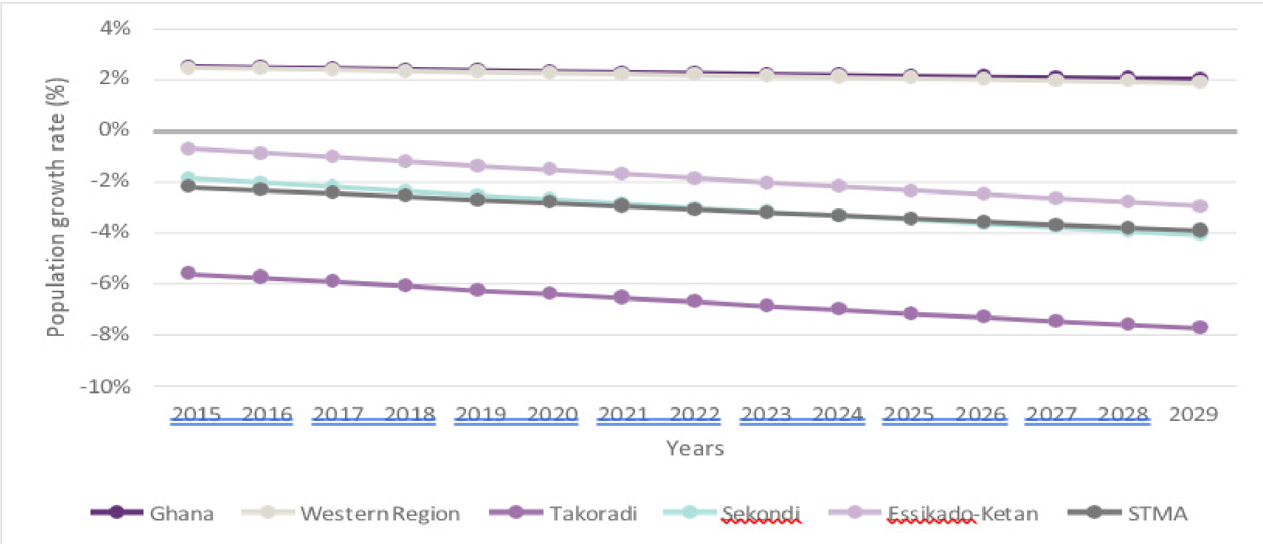
Table 4 provides an extract of the Ghana Population Estimates for 2015 to 2030, spaced in three-year intervals. Figure 11 shows the projection of the annual population growth rate (%) from 2016 to 2030, based on the U.S. Census Bureau data. A detailed study on the population growth and current and future socioeconomic development scenarios for STMA is needed to assist in interpreting this data, especially because the Census 2021 data was collected during the COVID-19 pandemic period.

3 https://esa.un.org/unpd/wup/

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
Western region	1 882 530	2 021 626	2 163 551	2 307 516	2 452 159	2 596 083
Takoradi	76,078	63,690	52,515	42,659	34,155	26,956
Sekondi	66,051	62,090	57,481	52,424	47,133	41,775
Essikado-Ketan	158,021	153,844	147,504	139,342	129,745	119,092
STMA	300 150	279 624	257 500	234 425	211 033	187 823

Figure 11 I Projection of the annual growth rate between 2016 to 2030



Source: data retrieved from the United States Census Bureau

The population pyramid included in Figure 10 shows the distribution of ages across the STMA population divided down the centre between male and female members of the population clustered by age groups in the horizontal bars. The graphic starts from youngest at the bottom to oldest at the top.

The population pyramid shows a decline in young people under the age of 15 and is consistent with the observed general decline in the population growth rate for STMA since the 2010 census. While this could be beneficial in terms of reducing the climate change risk with potentially less people living in more vulnerable areas, it is potentially a concern for long term economic growth and sustainability.

The economy of the Sekondi-Takoradi Metropolitan Assembly is made up of services (59 %), agriculture (21 %) and industry-related activities (19 %). An expansion in communication, energy, transportation, water, and sanitation infrastructure serves as a pull factor to attract migrants into the city in search of better opportunities leading to higher population densities. The high population density offers a large potential market for business activities. This contributes to the attraction of skilled workers, which allows the transfer of knowledge and skills in specialized sectors of the economy such as the oil and gas industry (STMA Metro Planning and Coordinating Unit, 2021).The private sector is the engine of growth of the economy in STMA but an economy with a large proportion of the private sector in informal jobs is an impediment to achieving accelerated economic growth and development. This is because it is very difficult, if not impossible to tax the self-employed (with or without employees) who are mostly in the informal economy (e.g. market and street vendors).

It follows therefore that with such a low tax base, the Metropolis may not receive sufficient revenue from the Internally Generated Fund (IGF). The higher ratio of people in service and sales accounts for the commercial activities in the Metropolis, but this includes mainly retail and wholesale activities which are typically in the informal sector (STMA Metro Planning and Coordinating Unit, 2021).

There are two main sources of water supply to Sekondi-Takoradi and nearby towns in the Shama and Ahanta West Districts. These water treatment plants are the Daboase Headworks which abstracts water from the Pra River and the Inchaban Headworks (constructed in 1928) which treats raw water taken from a dam on the Anankwar River (constructed in 1969) (Coastal Resources Center, 2013).

Sanitation and waste management is the sole responsibility of the Metropolitan Assembly. Presently four (4) waste management services are engaged to perform this major responsibility through the adoption of the polluter-pay principle (STMA Metro Planning and Coordinating Unit, 2021).

Households in Sekondi-Takoradi have high levels of access to electricity—97 percent of urban households in the Western Region have access to electricity (Ghana Statistical Service, 2022a) but reliability remains an issue. Relatively frequent electricity outages occur through the region, driven by transmission issues, low water levels in hydropower dams, and gas supply interruptions.

Appendix C provides more background information for the Sekondi-Takoradi Metropolitan Assembly.

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 socio-economic conditions including the dependency on high-risk sectors such as agriculture, as well as the institutional capacity to manage and mitigate the potential for increasing climate change related risks including floods and droughts. The future level of climate change vulnerability will be determined based on the socio-economic development pathway as described in the previous section and summaries below in terms of future vulnerability.

5.1 Current Vulnerability - Sensitivity and Adaptive Capacity

Due to its location in the coastal western region of Ghana, STMA is highly vulnerable and exposed to climate risks, including extreme weather events, sea level rise, and flooding. Various factors, including economic, social, human, and political resources, influence STMA's vulnerability to climate change.

5.1.1 Economic Vulnerability

Sekondi-Takoradi is an important centre of economic activity in Ghana, with a thriving port, oil and gas industries, and other sectors. The city has a strong social fabric, with community organizations, non-governmental organizations, and other groups working to support vulnerable communities and promote resilience to climate impacts. The STMA has systems established within the local government authority responsible for managing the city's infrastructure, services, and development. These systems and economic opportunities provide an opportunity for decision-making and action on climate change issues.

While commerce and industry-related activities are the major contributors to the economic development of STMA, agriculture and fisheries continue to play an essential role in the economy of the Metropolis, with agriculture providing both full-time and part-time employment for about 20% of the total population.

In addition to the commercial activities associated with the port, the Western Region of Ghana also contains several forts that are tourist attraction and also help in supporting the local economy. These facilities, however, are located along the coastline and are threatened by increased sea-level rise.

5.1.2 Physical/Environmental Vulnerability

Sekondi-Takoradi is a relatively urbanized Metropolitan Area and because of development expansion, limited areas of natural vegetation remain. Much of the southern and coastal parts of the district are settled, while the northern area contains some agricultural areas. There are however a few critical natural areas including limited remaining forested areas such as the Monkey Hill Conservation Forest and also mangroves in the coastal lagoons and Whin River estuary. This all help in reducing the potential impacts of sea level risk as well as increasing flooding risk and also help in reducing heat impacts.

Encroachment represents a more acute threat to the existing natural forest and wetland areas than changing climate, however changing climate conditions could threaten these critical natural areas through shifting climatic conditions and increase wildfire risk (high heat and drought conditions), sea level rise and increased rainfall intensity and associated risk of flooding. Threats from pests and microbes also increase with climate change as new invasive species move into the area which can be particularly dangerous for forest stands already weakened by drought and wildfire (Graziosi, Tembo, Kuate, & Muchugi, 2020). Urban tree cover has become a priority in recent years with numerous efforts to plant trees both in reserves and in the metropolitan area, for example the Sekondi-Takoradi Metropolitan Assembly plan to plant 10 000 fruit trees throughout the twin cities (Siabi-Mensah, 2022).

In addition to providing habitat for birds and other species, urban tree coverage can reduce heat island effects and mitigate potential human health risks from extreme heat as well as reducing flooding risks.

Wetlands and mangroves are also at risk from encroachment, fill, illegal mining, and pollution. Nationwide, mangrove coverage fell by nearly half between 2006 and 2014 (Nunoo & Agyekumhene, 2022). Residents of Sekondi-Takoradi have reported awareness of depleting wetlands in recent years. These areas provide important ecosystem services including habitat, particularly as a nursey and spawning ground for fish species important for nutrition and livelihoods, water filtration, flood protection, and materials provision (e.g., construction materials and fuelwood including for the smoking of fish).

5.1.3 Social Vulnerability and Adaptive Capacity

The most vulnerable groups within STMA are women (elderly and orphans), children, people with disabilities and low-income individuals and households in both a rural and urban setting. These groups are disproportionately affected by the loss of services when infrastructure fails 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 who may be disproportionately affected by health and other impacts caused by disruptions to basic services (Adshead, et al., 2022). Households dependent on primary economic activities such as small-scale fishermen and subsistence agriculture are the most vulnerable to the potential impacts of climate change as they are more directly exposed, and they have limited resources.

Sekondi-Takoradi faces challenges in building its adaptive capacities and reducing vulnerability due to limited financial resources, inadequate infrastructure, and insufficient technical capacity and expertise. However, by building on the existing strengths, include economic diversity, and addressing the challenges, the city can improve its adaptive capacity and build a more sustainable and resilient future.

The level of awareness about climate change risks and adaptation options also needs to be improved in STMA to enhance the adaptive capacity and enable existing systems to support the communities.

5.2 National and Sub-National SSPs

A parallel study has considered the development of local level socio-economic 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 socio-economic development scenarios were developed out on 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, low global population growth and slower economic development, leading to 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-fueled 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 way to achieve sustainable development. It is a world of intensive fossil fuel development, high energy demand and rapid technological progress, but 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, 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 volatile due to prevailing political uncertainties.

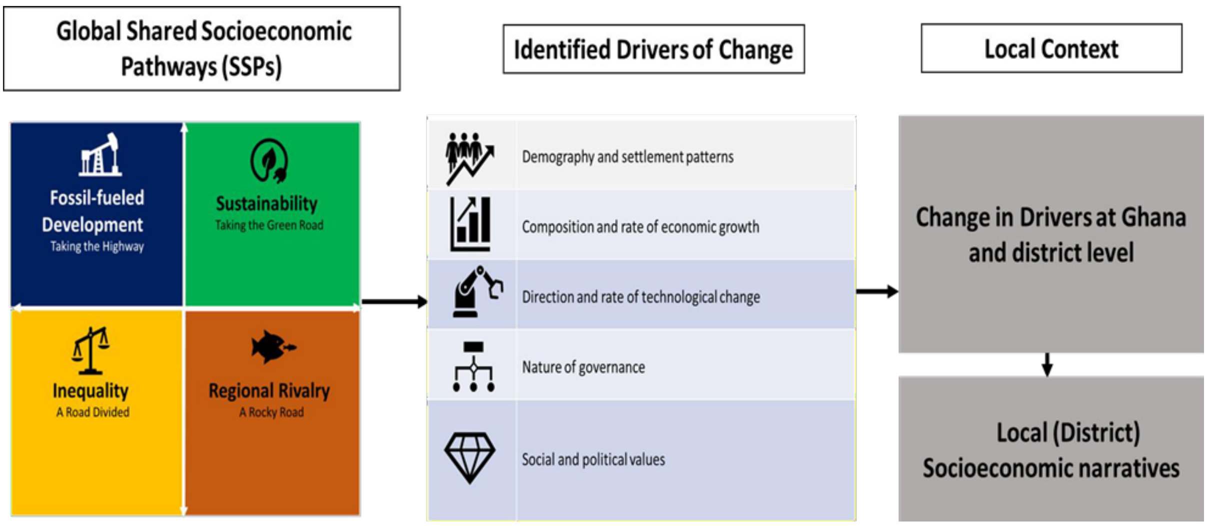
4. *Regional Rivalry – A Rocky Road:* This SSP is characterized by resurgent nationalism, competitiveness and security, along with weak global institutions. Other features are trade barriers, authoritarian governments and highly regulated economies. Economic development is slow but material consumption 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 socio-economic 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 12 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 12 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 through investments in ecological infrastructure and pro-active urban planning. Improvements in agricultural practices and successful water resources development through the One Village One Dam 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 also reduce 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. For coastal communities increased investments in coastal defences and including the protection and rehabilitation of coastal wetlands and mangroves also help in addressed some climate related risks.

Under this scenario, however, the oil extractive industry is reduced which could have a negative economic impact on the region unless sufficient investments are made to support a **just transition** and including the promotion of alternative and more sustainable industries to support the local economy with a particular focus on vulnerable communities and embracing sustainable urban planning practices.

The STMA will witness a slight increase in population due to a positive net-migration resulting from changes in the main economic activities of the area. The green path taken will result in a reduction in the operations of the crude oil industry forcing residents who worked in such industries to relocate in search of other job opportunities, ideally in the rural areas. On the other hand, the need for energy will lead to the development of renewable energy-generating industries such as thermal and solar plants. This will result in the inflow of new people to take up positions in such new industries. Additionally, the green path taken will lead to a rise in tourism activities due to cleaner environmental conditions further increasing the population of the area and local economic development.

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 that these benefits are used to reduce the vulnerability to climate change. This could include for example making investments 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 and overall increase in the vulnerability to climate change as well as other risk factors. STMA could potentially see a significant economic benefit associated with increased investments in oil and gas that could be used to reduce the vulnerability of local communities through increased diversity of economic opportunities, or if invested in improvements in critical infrastructure and coastal protection.

In the STMA, the high rate of economic growth will attract migrant workers from around the country and even from neighbouring countries such as the Ivory Coast to work in the extractive sectors of the local economy. The population of STMA will rise sharply and this will lead to pressure on the existing social amenities and other critical infrastructure in the metropolis because the local authorities will not be able to expand the capacity of such resources to accommodate the rate and pace of population increases.

The increase in the population of the STMA due to a growing economy will impact the socio-cultural, economic and land use activities of communities, especially those along the coast. These changes coupled with the sea level rise associated with global climate change will increase coastal erosion and inundation which will have devastating effect on the STMA. Communities and critical infrastructure along the coast will continue to be washed off by rising sea levels and consequential impacts on the shoreline. This will force people out of the settlements and also to create a number of internally displaced population who will seek shelter in unplanned neighbourhoods adding to an increasing number of slums.

Under the **Inequality - Road Divided** scenario, the the Sekondi-Takoradi Assembly 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 driver inequality with those who have the means being able to adapt to increase climate related risks by putting in their own water supply systems or flood protection, with the vast majority of the population 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 cooperation. There is limited inflow of aid in all forms, and this reduces the availability of funds to undertake relevant projects. In the STMA, the absence of international commitments will lead to a continued encroachment on the tropical forest and mangroves increasing the risk associated with both inland and coastal flooding. The STMA will also lack the funds necessary to protect critical infrastructure such as the port, roads, power station, and coastal forts. This will have a significant negative impact on the local economy as the disruptions to services increase.

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 varies 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. (Ministry of Foreign Affairs of the Netherlands, 2019).

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 inter-annual 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 percent 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 Observed Climate and Trends

The average annual temperature in Sekondi-Takoradi is currently just above 26.5ºC but has risen by approximately 1°C since the late 1970s. Since 2005 the mean annual and decadal temperatures have consistently been above 26°C. Figure 13 shows the mean annual temperature for the past 40 years, including the trend (dashed blue line). Annual temperature anomalies are shown in the lower part of the graph with blue indicating years colder than the average and red indicating warmer years.

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 possibility of increased dry spell durations (The World Bank Group, 2021a).

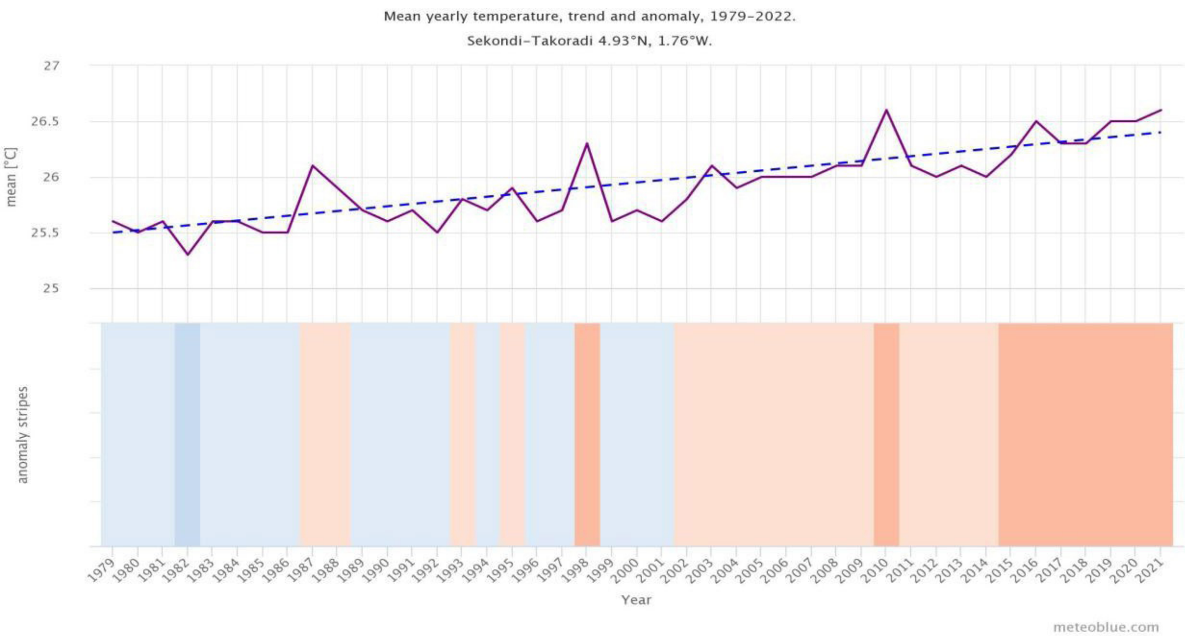
4 'Hot' day or 'hot' night is defined by the temperature exceeded on 10% of days or nights in current climate of that region and season.

5 'Cold' days or 'cold' nights are defined as the temperature below which 10% of days or nights are recorded in current climate of that region or season.

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

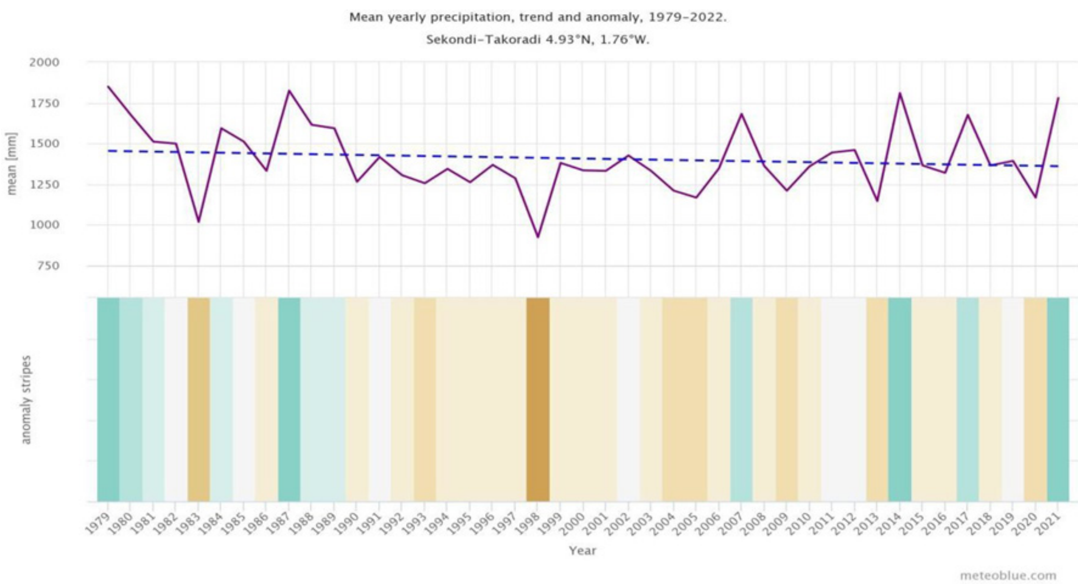
Figure 14 shows the annual precipitation and overall trend (dashed blue line) for the past 40 years. Since the late 1980s until the 2000s, a continuous reduction in annual precipitation was observed. Since then, there appears to be a small increasing trend in annual precipitation with alternating wet and dry years. In the lower part, the graph shows the annual precipitation anomalies, where green indicates years that are wetter than the average and brown indicates drier years.

Figure 13 I Mean annual temperature, trend, and anomaly in STMA, 1979-2022



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

Figure 14 I Mean annual precipitation, trend, and anomaly in STMA, 1979-2022



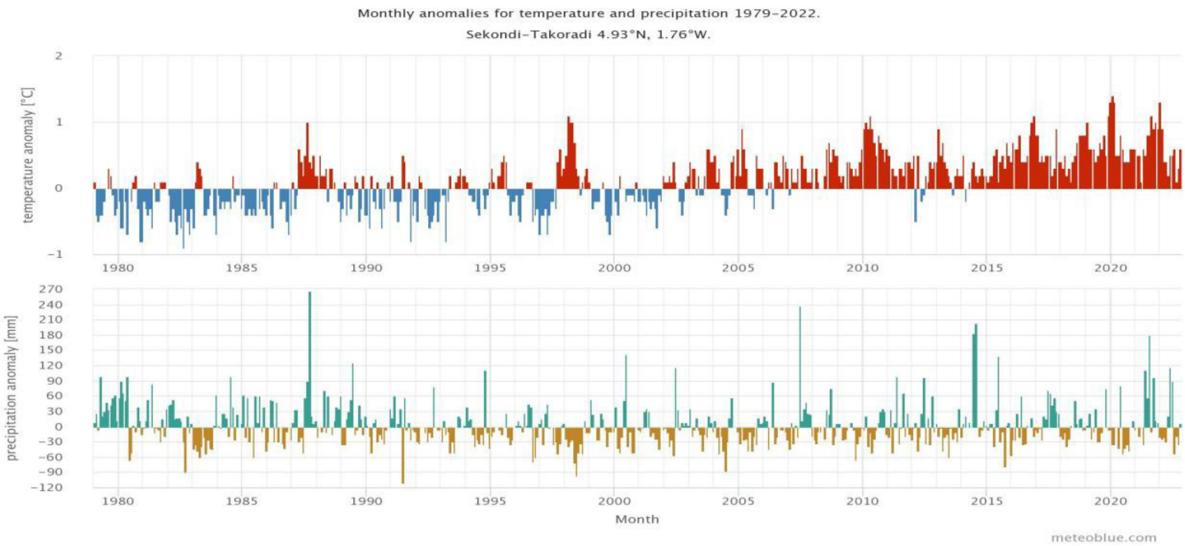
Source: (www.meteoblue.com, 2022)

Figure 15 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, by how much each month was warmer or colder than the average – red months were

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.

warmer and blue months were colder. It is possible to observe an increase in warmer months over the years. This reflects the global warming trend associated with climate change. The lower graph shows the monthly precipitation anomalies, if there was less or more precipitation that average – green months were wetter and brown months were drier. It is possible to observe that since 2000, the values of both wetter and drier months have been greater, especially for the wetter months which suggests a potential increase in wetter months possibly linked to flooding.

Figure 15 I Monthly anomalies for temperature and precipitation in STMA, 1979-2022



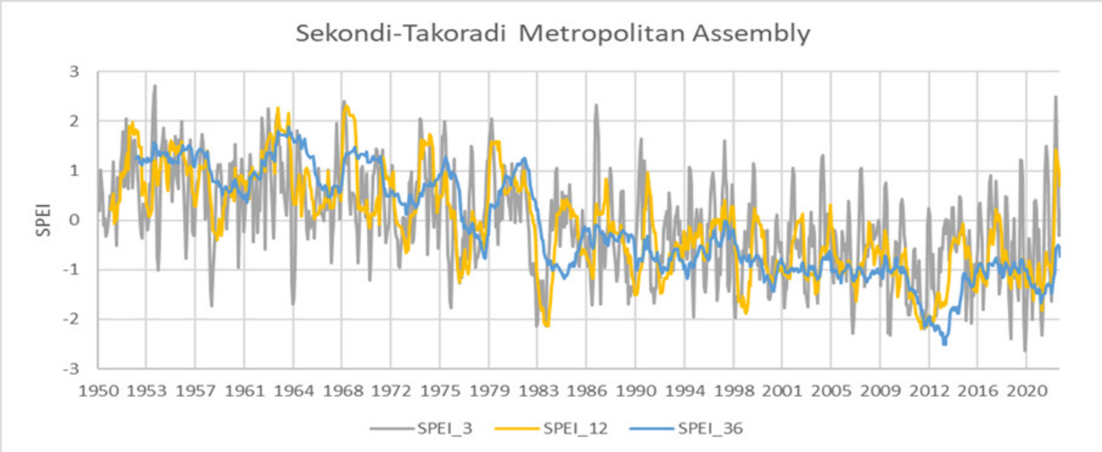
Source: (www.meteoblue.com, 2022)[8]

A preferred method for the analysis of drought conditions is to use the Standardised Precipitation and Evapotranspiration Index (SPEI), as it can account for the effects of both precipitation ad temperature variability in the context of global warming and the impact on drought. The SPEI represents the measure of the 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, with negative values indicating increased aridity, while positive values indicate wetter periods. This is an important understanding for the water sector regarding water quantity and quality of supply for human consumption and agriculture use as well as for the energy sector as reductions in water availability impacts river flow and hydropower generating capabilities (The World Bank Group, 2021a). Figure 16 shows the observed trends in drying (negative SPEI) and wetting (positive SPEI), for three different timescales, 3, 12 and 36 months, as an indicator of current trends for floods and droughts. From the figure it is clear that the conditions are becoming drier in Sekondi-Takoradi over time, particular the past decade but with increasing annual variability. However, the past decade, since 2012 shows a reduction in the drying trend with increased wetting.

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.

Figure 16 I Observed trends in the SPEI in STMA, 1950-2010



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

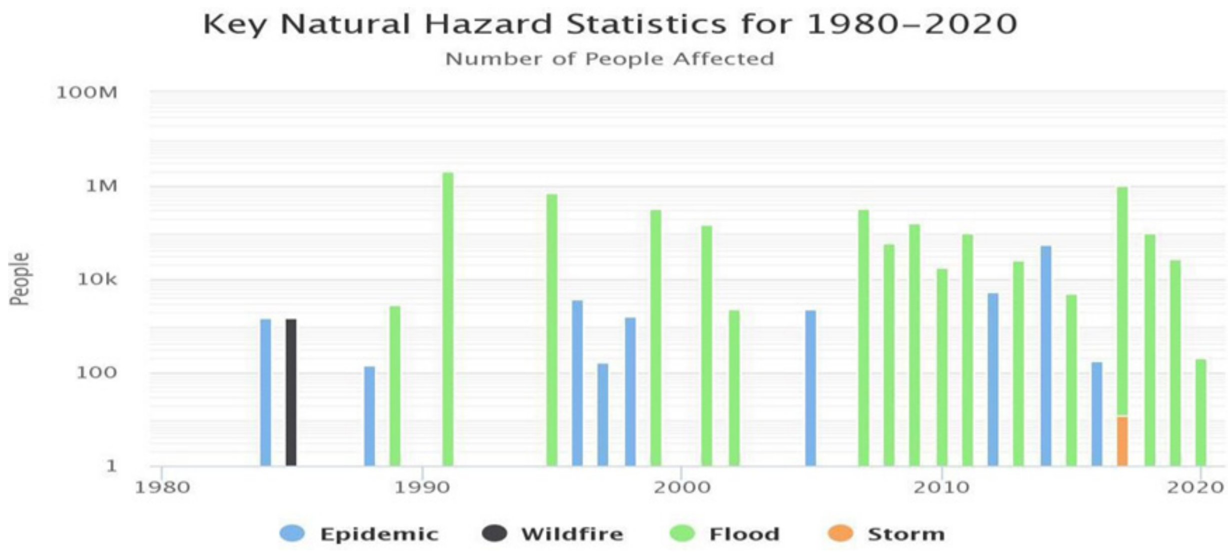
6.3 Observed Natural Hazard and Extreme Events

Ghana is highly exposed to extreme hydrometeorological conditions, such as floods, particularly in the northern Savannah belt, and faces associated risks of landslides. In the past 50 years, 22 major hydrometeorological events (19 flood events and three drought events) in Ghana have affected 16 million people with over 400 deaths (Pwamanng, Appah-Sampong, & Oppong-Boadi, 2020).

Rising sea levels, drought, higher temperatures, and erratic rainfall negatively impact infrastructure, hydropower production, food security and coastal and agricultural livelihoods. Approximately ¼ of the population of Ghana lives along the coast in rapidly expanding urban areas and are especially vulnerable to coastal flooding. Drought and reduced rainfall threaten access to reliable power sources, already erratic and insufficient. The climate and socio-economic environment in semi-arid, coastal and wetland areas make communities vulnerable to food insecurity and unstable livelihoods as well as leading to unsustainable agroecological systems, crop failure and unproductive rangelands (USAID, 2017).

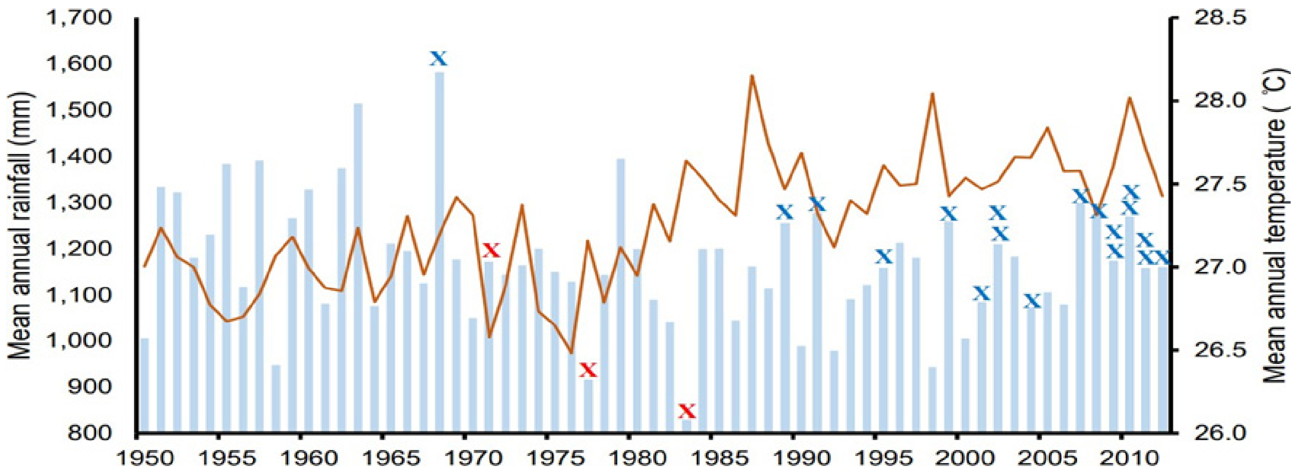
A summary of recorded natural hazard events that have occurred in Ghana since 1980 and the number of people affected is shown in Figure 17 from the Climate Change Knowledge Portal (CCKP). Figure 18 illustrates another record of extreme climate events (droughts and floods) relative to mean annual rainfall and mean annual temperature in Ghana from 1950 to 2012. These two figures indicate an increasing occurrence of flood related disasters in particular with these almost becoming a yearly occurrence since the late1990s. In contrast, although there are concerns related to increasing drought risk as a result of hotter temperatures and more erratic rainfall, there have been no major drought disasters since 1983.

Figure 17 I Summary of Key Natural Hazard Events for Ghana from 1980 to 2020



Source: WB Climate Change Knowledge Portal

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, National Climate Change Report, 2020, 2020)

The availability of historical information on catastrophic natural hazard events in Sekondi-Takoradi is limited, but there are several references and online articles suggesting that natural hazards, particularly floods are a regular event. These floods are however often linked to blocked and undersized stormwater system that cannot drain the water from the June heavy rains and not necessarily an indication of increasing frequency of extreme rainfall. Table 5 contains a list of climate related hazard events that have occurred in Sekondi-Takoradi and surrounding areas since 2009, compiled based on the information collected from newspapers and press releases publicly available on the internet.

Table 5 I Historical catastrophic hazard events occurred in STMA and surrounding areas.

Date	Hazardous Event	Location	Impact	Reference
February 2023	Limited water supply (water shortage) due to the low level of water at the intake points of the Ghana Water Company Limited (GWCL) in the region.	Sekondi-Takoradi Metropolis	The activities of illegal miners upstream of the River Pra, causing severe siltation at the plant's intake. The high silt deposits have drastically reduced the volume of raw water available for abstraction. The dry season has also exacerbated the problem of raw water unavailability	https://citinewsroom. com/ 2023/02/illegal-mining-causing-water-shortages-in-sekondi-takoradi-gwcl/ https://3news.com/ sekond i-takoradi-residents-asked-to-brace-up-for-worsening-water-supply/
June 2022	Floods due to torrential rainfall	Sekondi-Takoradi Metropolis Communities like Bankyease, Assakae, parts of Anaji, Whindo, Appollo Junction, Apremdo, Effia, Kwesimintsim, and racecourse were affected. Parts of Kojokrom, Essikado, Takoradi Zenith, Anaji Choice Mart area, and some suburbs in the Metropolis were under water.	Several communities in the Sekondi-Takoradi Metropolis were submerged following torrential rains. Properties running into millions of cedis have also been destroyed by the flood and the majority of the residents had their rooms flooded owing to the volume of rain.	https:// dailyguidenetwork. com/parts-of-sekondi-takoradi-submerged-after-heavy-downpour/
April 2022	Coastal flooding caused by tidal waves	Coastal areas in the Western and Volta Region and Ada in the Greater Accra region	Property destroyed and many residents displaced. The tidal wave caused the sea to overflow its banks, spreading through the road from Sekondi Gate Ekyir through to Nkontompo.	https://ghanaplus.com/news/tidal-waves-hit-parts-of-sekondi-residents-call-for-sea-defence/ https://gh.opera. news/gh/ en/ society/5f12d2356e09 8c2fff4758f9ea20c92d
March 2022	Erosion (Coastal erosion damaging road infrastructure)	Sections Of Cape Coast-Takoradi Highway, At About 1 Km from Heritage Beach Resort	Damage of road infrastructure, disrupting traffic and pose a safety risk to pedestrians as the walkway is gradually being washed away.	https://www.ghanaweb. co m/GhanaHomePage/ New sArchive/ Erosion-gradually-caving-in-portions-of-Cape-Coast-Takoradi-Highway-1497674

January 2022	Limited water supply (water shortage) due to low water levels at the treatment plant	Sekondi-Takoradi Metropolis	The Ghana Water Company Limited (GWCL), had to ration water supply in the Sekondi-Takoradi metropolis, during an undetermined period	https://www.afrik21.africa/ en/ghana-gwcl-rationing-water-distribution-in-sekondi-as-dry-season-begins/ https://www.graphic.com.gh/news/general-news/water-shortfall-hits-sekondi-takoradi-cape-coast.html
June 2021	Floods due to torrential rainfall	Sekondi-Takoradi Metropolis Apowa area, Market Circle, Beach Road, Shippers Council, Melcom Road, Asempa Hotel, and its environs	Several roads and buildings have been inundated	https://www.myjoyonline.c om/several-hours-of-downpour-leaves-parts-of-sekondi-takoradi-flooded/
October 2019	Floods due to torrential rainfall and blocked drains with litter, sand and weeds	Sekondi-Takoradi Metropolis	Several roads and buildings have been inundated; several residents have been displaced.	https://www.ghanaweb.co m/GhanaHomePage/New sArchive/80-families-displaced-by-floods-in-Sekondi-Takoradi-788850
June 2019	Floods due to severe weather including strong winds and heavy rain affected parts of Ghana from 30 May, 2019	Accra and parts of Western Region	Five people died when their home in the village of Ngyeresia, Essipong district, collapsed under pressure from flood water. In a separate incident, 5 other people died in the same area after a tree was uprooted by strong winds and fell onto their home.	https://floodlist.com/africa/ floods-accra-western-region-may-june-2019
May 2017	Floods due to torrential rainfall and blocked gutters with litter and sand	The entire community in the Sekondi-Takoradi metropolis has been submerged, including Nkotompo Effia-Kuma, Cocoa Villa, Takoradi and Ntakofo, Bakano and Bakakyir in Sekondi	The rains, left most roads in the Metropolis impassable by both vehicles and pedestrians and most houses were submerged.	https://www.pulse.com.gh

June 2014	Floods due to torrential rainfall	Sekondi-Takoradi Metropolis	/news/flooding-heavy-downpour-floods-sekondi-takoradi/3jwhtrc	https://www.modernghana.com/news/551577/ seko ndi-takoradi-floods-again.html
June 2013	Floods due to torrential rainfall and blocked drains with litter and sand	Sekondi-Takoradi Metropolis Some suburbs affected were Tanokrom, Anaji West, Namibia, Cocoa Villa, Egyinabowa-Kakam and Effia-Nkwanta Regional Hospital roundabout.	Roads and buildings have been inundated	https://www.ghanabusinessnews.com/2013/06/02/nadmo-says-has-no-relief-items-as-flood-hits-parts-of-sekondi-takoradi/
June 2010	Landslide due to heavy rain	Sekondi-Takoradi	Slight landslide along Sekondi-Takoradi main road, uprooting 3 large trees on the hill near the Paa Grant Roundabout in Takoradi, blocking the road.	https://www.ghanaweb.co m/GhanaHomePage/New sArchive/Rains-in-Takoradi-uproots-trees-184908
June/ July 2009	Floods due to several hours of rain and subsequent heavy down pours along the coastal and forest belt of Ghana. The floods were caused by choked and narrow gutters and the erection of structures and buildings on watercourses.	All over the country. In the Western Region the affected communities are: Sekondi Takoradi, Sanzule and Enchi. Coastal towns like Ellembelle and Jomoro were flooded with large portions submerged in water.	Massive destruction of private and public properties in most communities in the western parts of Accra, Eastern, Volta, Central, Western and Ashanti Regions.	https://reliefweb.int/ report/ ghana/ghana-floods-dref-operation-no-mdrgh002
July 2003	Landslide due to sea erosion (coastal erosion due to sea level rise)	Nkontompo (suburb of Sekondi)	It was estimated that 368 families have been rendered homeless as a result of sea erosion at Nkontompo	https://www.ghanaweb.co m/GhanaHomePage/New sArchive/artikel.php?ID=3 8953

Figure 19 | Examples of the impact of coastal erosion in Nkontompo

Coastal Erosion Risk Narrative

In July 2003, the landslide in Nkontompo, a suburb of Sekondi, was a headline in the regional news. It was estimated that 368 families have been rendered homeless due to coastal erosion.

This was not an isolated event and is not only in Ghana that the coastline is threatened by coastal erosion. The number of people at risk from rising sea levels and increased storm surges is increasing and coastal communities along West Africa's shoreline are becoming progressively more vulnerable to the potential hazards including coastal erosion, coastal inundation and flooding, and coastal resource degradation.

It was estimated that about 37% of Ghana's coastal land was lost to erosion and flooding between 2005 and 2017. Research published in 2014 revealed that the coastline of Nkontompo was receding at a rate of approximately 2 metres per annum over a period of 23 years (1979-2003). While shoreline erosion and accretion are natural phenomena, human activities and global warming are increasing the rate.

Ghana's eastern coast has been identified as the most vulnerable, mainly after the construction of the Akosombo dam, on the Volta River in 1965, which considerably reduced the sediment input on the east coast, causing sand deficits on the surrounding beaches. However, on the west coast oil and gas production and the subsequent increased migration of people in search of jobs has caused extensive coastal and environmental degradation, including the loss of coastal vegetation like mangrove swamps and wetlands.

This is exacerbating the coastal erosion risks. Illegal sand mining along the coast also disturbs the equilibrium of the beach system and either initiates or intensifies coastal erosion.

The increasing rate of coastal erosion is also threatening critical infrastructure such as roads and power stations as well as several important cultural sites like coastal forts that support the tourism economy.

In an attempt to address the coastal erosion issue, the government of Ghana has been providing largely re-active and localised solutions, usually involving building hard engineering coastal defence structures, such as seawalls along the shore to stabilize the coastline However while these structures do stabilise the shoreline at the protected section, they can result in aggravated erosion risks somewhere else.

The vulnerability of the coastal zone, and associated communities and critical infrastructure, is expected to increase significantly in the near future, due to sea level rise, and increased severity of coastal storms, which will likely increase coastal erosion rates and the risk of flooding of the coastal low-lying areas.

In order to reduce the risks associated with increasing coastal erosion effectively a more pro-active and holistic approach is necessary, considering the coastal dynamics, human activities and developments, the interrelationships of coastal systems, cause-effect relationships and environment concerns. Nature-based solutions (NbS), such as the replanting of mangroves and coconut palms should be considered.

Furthermore, more emphasis should be placed on prevention. It is crucial to update the Integrated Coastal Zone Management Strategy (ICZMS), and develop an Integrated Coastal Management Policy (ICMP).

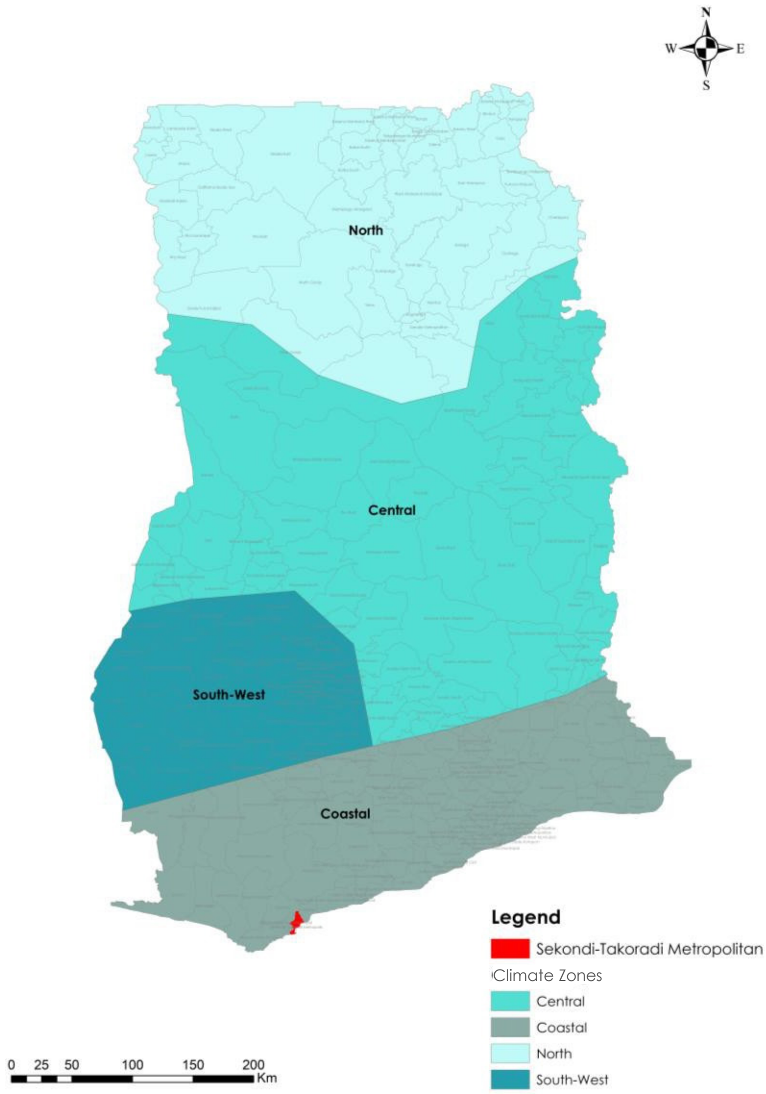
Photograph credit G. F. A. Olympio and S. Amos-Abanyie, 2003 & 2009

Source: http://dx.doi.org/10.4314/just.v33i3.5

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, Southwest, 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 20 shows the four climate zones, where it is possible to observe that the STMA is located in the Coastal Climate Zone.



6.4.1 Self-Organising Maps (SOMs) Analysis for Coastal Zone

As part of the Climate Scenarios Analysis Report for Ghana (See separate report), individual climate scenarios were identified for each of the four climate zones 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: RCP 2.6,

4.5 and 8.5. 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 bene identified from the CORDEX dataset which can then be used to provide additional information on specific climate variables for further study. Table 6, Table 7 and Table 8 show the results of joint pathways analysis for the Coastal Climate Zone under RCP2.6, RCP4.5 and RCP.5, respectively.

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

Scenario	Likelihood of Individual Scenarios	Expected Impacts Temperature (°C) / Rainfall (ratio)		
	Coastal	2035	2055	2075
A26	1 35%	0.5/1.05	0.5/1.05	0.5/1.05
B26	3 20%	1.5/1.05	1.5/1.05	2.0/1.05
C26	4 15%	1.0/1.00	1.0/1.00	1.0/1.00
D26	2 30%	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
UE B26	✓	1.0/1.10	1.5/1.10	1.5/1.05
LE A26	✓	1.0/0.95	1.0/0.95	1.5/0.90

Table 7 l Results of joint pathways analysis for the Northern Climate Zone under RC P4.5

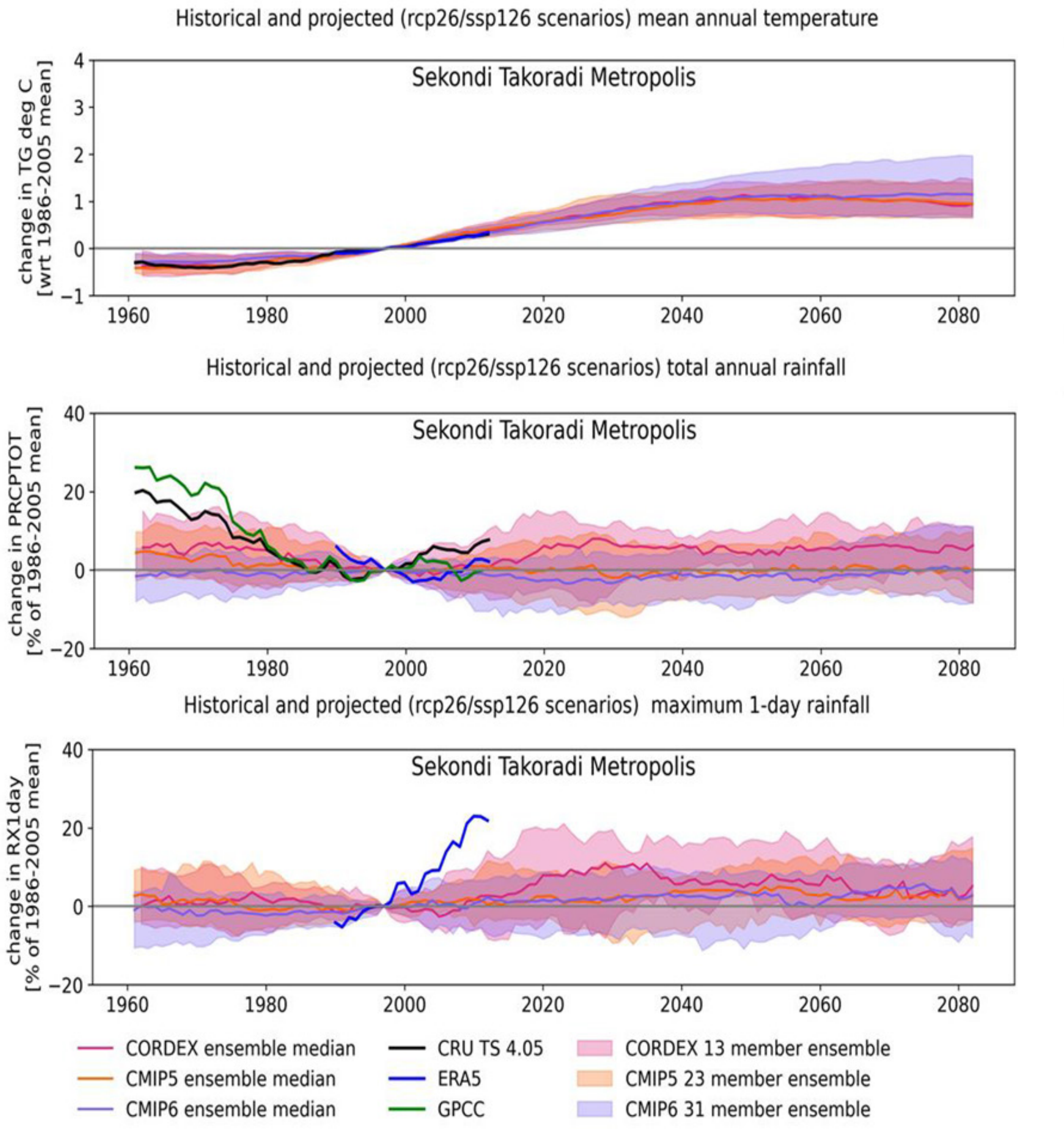
Scenario	Likelihood of Individual Scenarios	Expected Impacts Temperature (°C) / Rainfall (ratio)		
	Coastal	2035	2055	2075
A26	1 35%	0.5/1.05	0.5/1.05	0.5/1.05
B26	3 20%	1.5/1.05	1.5/1.05	2.0/1.05
C26	4 15%	1.0/1.00	1.0/1.00	1.0/1.00
D26	2 30%	1.0/0.95	1.5/0.95	1.0/0.95
UE A26	✗	0.5/1.15	1.0/1.15	1.5/1.10
UE B26	✓	1.0/1.10	1.5/1.10	1.5/1.05
LE A26	✓	1.0/0.95	1.0/0.95	1.5/0.90

6.4.2 Plume Plots Analysis for STMA

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.

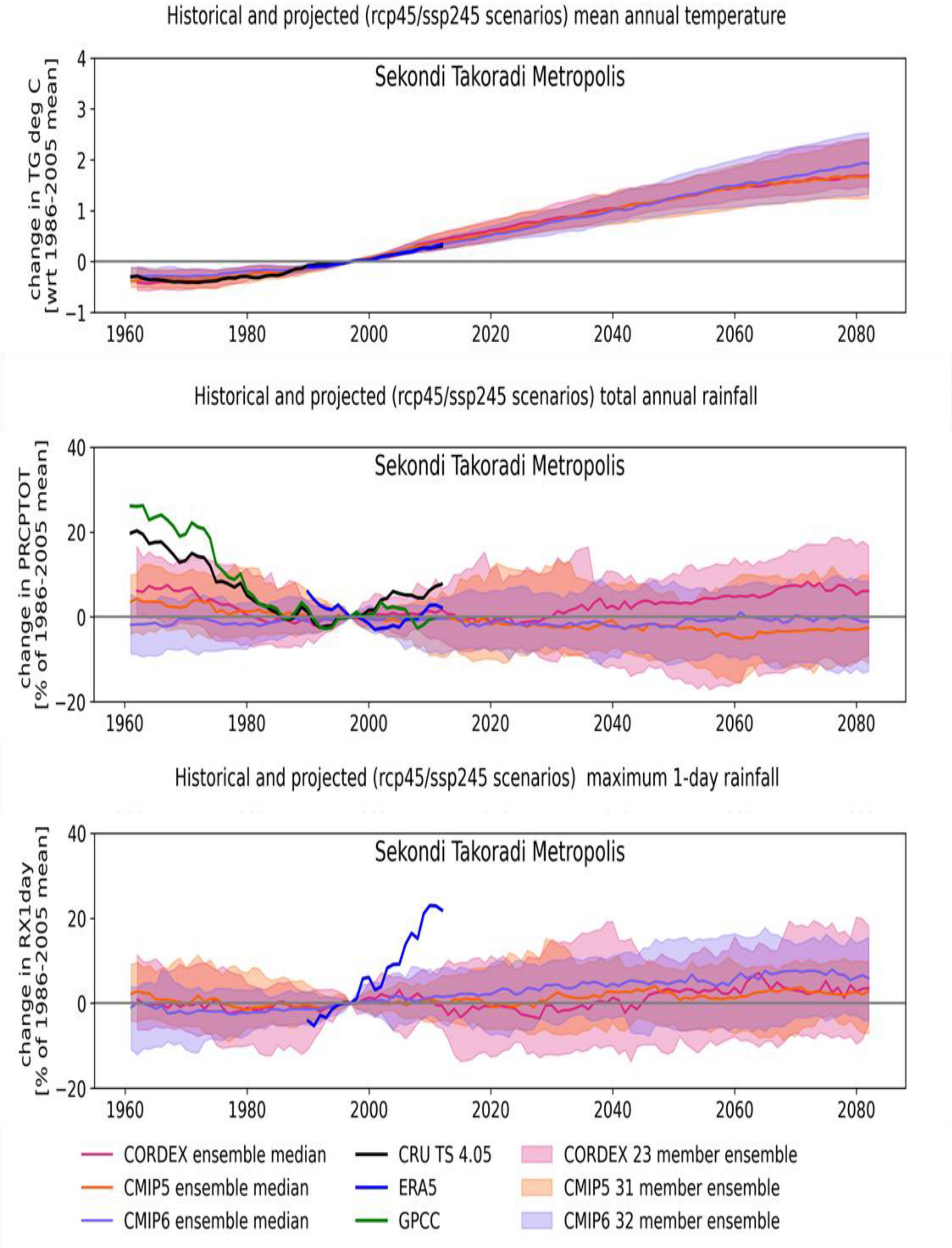
The plume plots showing the range of possible climate scenarios derived from both the CMIP5 and CMIP6 ensemble of climate models as well as the CORDEX dataset of downscaled climate scenarios (CMIP5 only) for STMA are shown in, Figure 21, Figure 22 and Figure 23**.** These represent the combined global 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 out to 2100. The plots also show the observed historical climate data from multiple sources.

Figure 21 I Plume plots illustrating the evolution of mean annual temperature, total annual rainfall and maximum 1-day rainfall, in STMA in simulations of historical and future climate in three ensembles under RCP2.6/SSP1-2.6 scenarios



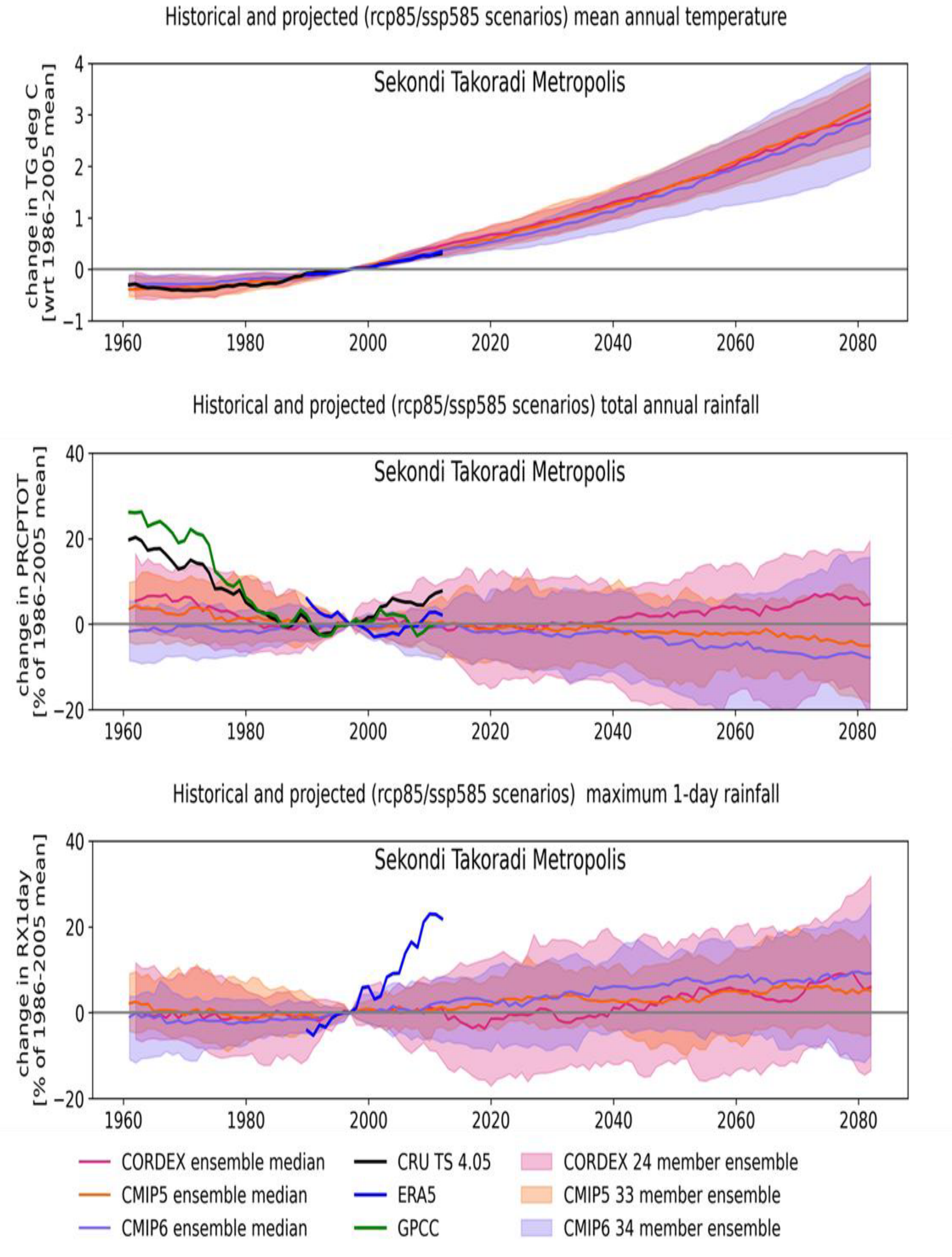
Note: All lines represent 20-year running averages calculated on annual values

Figure 22 | Plume plots illustrating the evolution of mean annual temperature, total annual rainfall and maximum 1-day rainfall, in STMA in 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 23 | Plume plots illustrating the evolution of mean annual temperature, total annual rainfall and maximum 1-day rainfall, in STMA in 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 Summary of Future Climate Change Scenarios

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

- **strong confidence** message of **increases in air temperatures** manifested in all scenarios and all the four climate zones identified for Ghana. Those 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 21st century under **RCP26/SSP126, RCP45/SSP245 and RCP85/SSP585** respectively.
- **moderate to low confidence** message of **weak changes** (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, independently of emission scenario. That **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 is shown in Table 9. The expected likelihood of the scenarios for the Coastal Climate Zone based on the SOMs analysis is also included in the table. The data for the SOMs analysis is based on the available CORDEX data representing CMIP5 projections.

Table 9 I Change in critical climate variables for STMA relative to the base period for the representative climate models representing the different future climate scenarios (CMIP5)

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 of Individual Scenarios		35%	20%	15%	30%	✓ (A)	✓ (B)	35%	20%	15%	30%	✓ (A)	✓ (B)	35%	20%	15%	30%	✓ (A)	✓ (B)
TG	27.0	2%	4%	3%	3%	4%	3%	2%	5%	3%	3%	3%	5%	2%	5%	3%	3%	3%	5%
TXx	29.3	2%	4%	3%	3%	3%	3%	2%	5%	3%	3%	3%	5%	2%	5%	3%	3%	2%	5%
SU30	1	124%	254%	295%	295%	225%	238%	76%	306%	290%	290%	184%	294%	146%	261%	271%	271%	104%	306%
PRCPTOT	94	11%	10%	18%	18%	-17%	9%	11%	24%	9%	9%	2%	17%	-7%	9%	3%	3%	3%	3%
Rx1day	12	30%	154%	172%	172%	-113%	44%	68%	222%	128%	128%	39%	172%	29%	104%	54%	54%	33%	62%
RCP 4.5																			
Likelihood of Individual Scenarios		45%	40%	✗	15%	✓ (A)	✓ (A)	45%	40%	✗	15%	✓ (A)	✓ (A)	45%	40%	✗	15%	✓ (A)	✓ (A)
TG	27.0	3%	3%	✗	3%	4%	3%	5%	4%	✗	4%	5%	4%	6%	5%	✗	5%	5%	5%
TXx	29.3	3%	2%	✗	2%	4%	2%	4%	3%	✗	4%	5%	4%	5%	4%	✗	4%	5%	4%
SU30	1	201%	111%	✗	9%	193%	9%	321%	112%	✗	24%	259%	24%	376%	206%	✗	84%	303%	84%
PRCPTOT	94	-15%	8%	✗	5%	0%	5%	-11%	3%	✗	22%	5%	22%	-7%	15%	✗	21%	9%	21%
Rx1day	12	-128%	-48%	✗	-48%	-77%	-48%	-40%	-125%	✗	124%	-63%	124%	-37%	30%	✗	217%	-51%	217%
RCP 8.5																			
Likelihood of Individual Scenarios		30%	30%	40%	✗	□ (A)	□ (A)	30%	30%	40%	✗	✓ (A)	✓ (A)	30%	30%	40%	✗	✓ (A)	✓ (A)
TG	27.0	3%	4%	4%	✗	5%	3%	5%	6%	7%	✗	9%	5%	7%	9%	10%	✗	12%	7%
TXx	29.3	2%	3%	5%	✗	5%	2%	4%	5%	8%	✗	8%	4%	6%	8%	10%	✗	11%	6%
SU30	1	136%	321%	274%	✗	252%	136%	211%	487%	490%	✗	398%	211%	331%	663%	621%	✗	580%	331%
PRCPTOT	94	-8%	8%	2%	✗	-9%	-8%	-4%	8%	10%	✗	7%	-4%	-9%	11%	26%	✗	-9%	-9%
Rx1day	12	-101%	84%	24%	✗	-21%	-101%	52%	101%	134%	✗	228%	52%	32%	145%	169%	✗	60%	32%

* *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, precipitation remains highly variable with the latest **CMIP 6 model results shown in** Table 10**. Most models** suggest the potential for more **wetting by the end of the century** over the coastal climate zone, but **further analysis is required** to clarify these results. Temperature is expected to increase for STMA with the greatest increases in temperature for the higher emission scenarios.

Table 10 I Range of the expected change in critical climate variables for STMA relative to the base period for different emission scenarios as per the latest CMIP6 global model results. The values indicate the ensemble mean (Q50), 10th (Q10), and 90th (Q90) of the range of model projections.

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	27.0	2%	3%	5%	3%	4%	7%	3%	4%	7%
TXx	29.3	2%	3%	5%	2%	4%	6%	3%	4%	7%
PRCPTOT	94	-12%	-1%	7%	-8%	-2%	6%	-9%	0%	11%
Rx1day	12	-55%	25%	97%	-74%	-12%	82%	-28%	44%	114%
RCP 4.5										
TG	27.0	2%	3%	4%	4%	5%	7%	5%	7%	9%
TXx	29.3	2%	3%	4%	3%	5%	7%	4%	6%	8%
PRCPTOT	94	-9%	-1%	4%	-10%	-1%	9%	-15%	0%	10%
Rx1day	12	-26%	37%	114%	-63%	39%	149%	-27%	47%	147%
RCP 8.5										
TG	27.0	2%	3%	5%	4%	7%	9%	6%	10%	14%
TXx	29.3	2%	3%	5%	3%	6%	8%	4%	9%	13%
PRCPTOT	94	-14%	-2%	8%	-21%	-5%	6%	-24%	-9%	15%
Rx1day	12	-90%	40%	115%	-47%	63%	161%	-74%	77%	188%

TG - Daily Mean Temperature; TXx - Maximum temperature; PRCPTOT - Total Annual Precipitation; Rx1day - Maximum 1-day total precipitation

6.5.1 Temperature

In the future, there is a likelihood for a significant increase in temperature in the coastal climate zone.

STMA will see temperature increase from 1.5 °C under RCP 2.6 to 3.5/4 °C under RCP 8.5, with RCP

4.5 suggesting a mid-point of about 2.0 °C, by the end of the century. As usual, RCP 8.5 represents a step change in temperature. However, the plume plots, particularly when incorporating CMIP 6, suggest an even greater temperature increase of another 0.5 °C. There is a risk of significantly higher temperatures for Sekondi-Takoradi MA even at lower GHG concentration scenarios.

6.5.2 Extreme Heat

Extreme heat is defined as the hot days with a maximum above 30ºC (SU30). Sekondi-Takoradi is a coastal city that currently enjoys temperatures of around 26.5ºC. However, the current situation is expected to change as extreme heat events are expected to be more frequent and intense over time. Currently however there is only on average 1 day per year above 30ºC. As a result, even small increases in the number of very hot days will represent a significant percentage increase. The total number of very hot days may still however be small and as a result these numbers are not presented.

6.5.3 Precipitation

There is a roughly equal chance of small increases and decreases in annual average precipitation compared to the base years. Typically, around 10% increase and/or decrease with the mean being no-change. The extremes suggest that the change is possible of up to 20% +/-. The plume plots suggest there is a relatively good match in the precipitation scenarios and the plume plots suggesting that the scenarios do a relatively good job of capturing the possible variation at RCP 2.6 but not RCP 4.5 or RCP 8.5 where there is chance of significant increases in rainfall - possibly 20-30% greater increases.

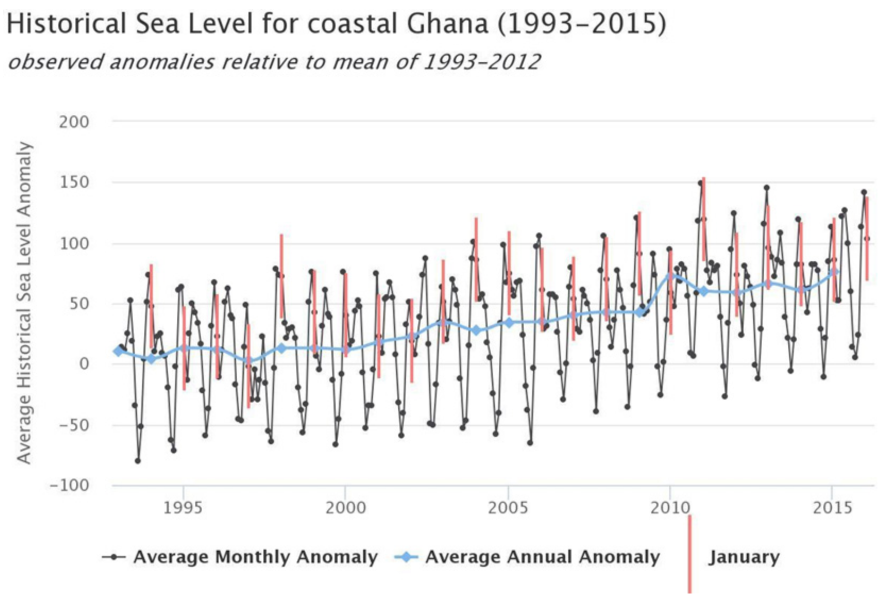
6.5.4 Extreme Rainfall

Maximum 1-day total precipitation is expected to increase under almost all future climate scenarios. The Upper Extreme (UE) model projected an increase of about 78%. The projections suggest possibility of an increase in extreme rainfall projections especially under the high emission scenario. This will have a significant impact on the potential for increased flood risk in Sekondi-Takoradi. In terms of the latest CMIP6 projections, the maximum 1-day rainfall is expected to increase by between 25% and 40% even over the next decade with the 90^{th} percentile showing over 100% increase.

6.5.5 Sea level rise

Currently, the annual global sea level rise is approximately 3 mm per year. Ghana is above global averages with around 4mm per year as shown in Figure 24. The IPCC has predicted with high confidence that the sea level will continue to rise at an increasing rate. Global mean sea level rise will cause the frequency of extreme sea levels events such as high tides, storm surges, strong winds, and changes in ocean currents at most locations to increase (IPCC,2014). By 2100, sea levels near Sekondi-Takoradi are expected to rise by approximately 0.4 meters by 2100 relative to historical sea levels under RCP 4.5, exacerbating the risk of coastal erosion and flooding (World Bank, 2021).

Figure 24 I Historical monthly and annual sea level anomaly (in cm) for coastal Ghana (1993-2015) – observed anomalies relative to mean of 1993-2012



Source: (The World Bank Group, 2021d)

Rising sea levels create not only stress on the physical coastline, but also on coastal ecosystems. Saltwater intrusions can contaminate freshwater aquifers, many of which sustain municipal and agricultural water supplies and natural ecosystems. As global temperatures continue to warm, sea level will keep rising for a long time because there is a substantial lag to reaching an equilibrium.

7

Potential Impacts for Priority Risk Domains

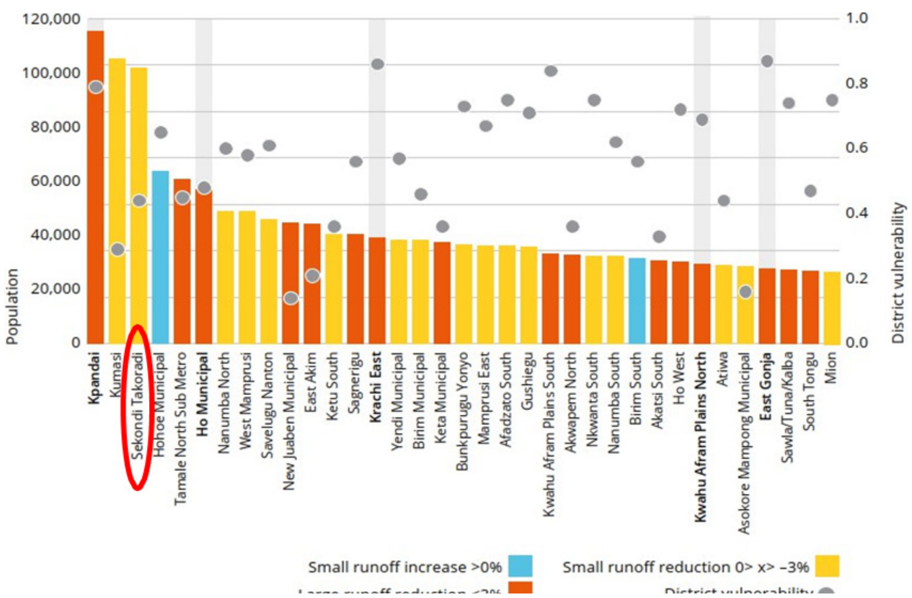
The potential impact of climate change on the priority risk domains are described here, including:

- Water Resources
- Coastal Erosion
- Flooding
- Ecosystems
- Energy Security
- Transport Systems
- Fisheries

7.1 Water Resources

Climate change is expected to contribute to a small reduction in runoff for the area around Sekondi-Takoradi. 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 mean annual runoff except during periods of very high flow which will causing increased risk of flooding. This will impact on local surface and ground water resources, but not necessarily on larger integrated water supply systems.

Figure 25 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 could contribute to an overall reduction in the availability of surface water (and potentially also groundwater) particularly if there is limited storage capacity or effective water resource management. As more intense rainfall increases the surface runoff increases too, contributing to erosion of the topsoil and sedimentation in the riverbeds. Reduced rainfall could limit ground water recharge and exacerbate saline intrusion and reduce of vegetation cover. Additionally reduced rainfall could also reduce dilution of contamination/ pollution in the rivers thus worsening water quality.

The location of the freshwater–saltwater interface along the coast is an essential factor in the ecological and socio-economic dynamics of coastal communities. However, the movement of saline water into freshwater aquifers, which leads to groundwater quality degradation, is one of the main problems in the coastal regions of Ghana (UNESCO-IOC, 2021). The western coast, where annual rainfall is about 2 000 mm, is also oddly filled with acid sulphate clay soils and salt-affected soils (EPA, 2003).

These degraded soils cover over 10 000 km2 (Gulzar, 2014). Apart from their high salt content and high acidity, most of these soils are heavy-textured, poorly drained with columnar structures (Amisigo, McCluskey & Swanson, 2015). Recorded cases of salinization occurrence on Ghana's coast calls for primary concern because most of the country's population is concentrated within this zone, and the urbanisation rate is also alarming. Most of these coastal regions rely on groundwater as their primary source of freshwater for industrial and agricultural purposes (UNESCO-IOC, 2021).

Mining is predominant in the southwestern river system and in this area pollution of surface water and groundwater has been observed because of the use of cyanide and other poisonous chemicals (WWF, 2020). The quality of water from the Pra River is also degraded by illegal gold mining operations, locally known as galamsey. This activity results in mercury pollution and sedimentation due to disturbance of the riverbed. It is worth noting that the Inchaban and Daboase water treatment facilities have not been designed to remove mercury and other heavy metals from the water supply.

Besides, the presence of high sediment loads in the water disrupts the normal functioning of the treatment facility. Together, these pose additional health risks to the populations that depend on these sources for their potable water supply. (Coastal Resources Center, 2013) Additionally, the diminishing water quality significantly increases water treatment costs and the decreasing dry season flows has an impact on the quantity of water available for abstraction and this could be impacted by climate change.

The intrusion of seawater in the soil threatens biodiversity along with crop yields, and the leaching of salts from areas affected by these processes would increase the salinity of water bodies nearby, destroy infrastructure and the economy in the long run. Over the coming decades, changing climate, growing coastal population, and increased sea-level rise will raise the salinity of the coastal zone aquifers of Ghana, affecting in various ways its population (UNESCO-IOC, 2021).

7.2 Coastal Erosion

Coastal erosion and its associated shoreline retreat problems are a serious threat to life, safety, property, economic development, and livelihoods of some Ghanaians, as over 70% of the major industries, urban settlements, tourism, heritage, and conservation sites are located in the coastal zone (World Bank, 2020). The shoreline in Western Ghana is made up of sandy beaches broken up by small rocky outcrops (Alves, Angnuureng, Morand, & Almar, 2020). The loose sediment of the beaches is constantly shifting under the energy of waves and wind, and in this area, it has been eroding for many years.

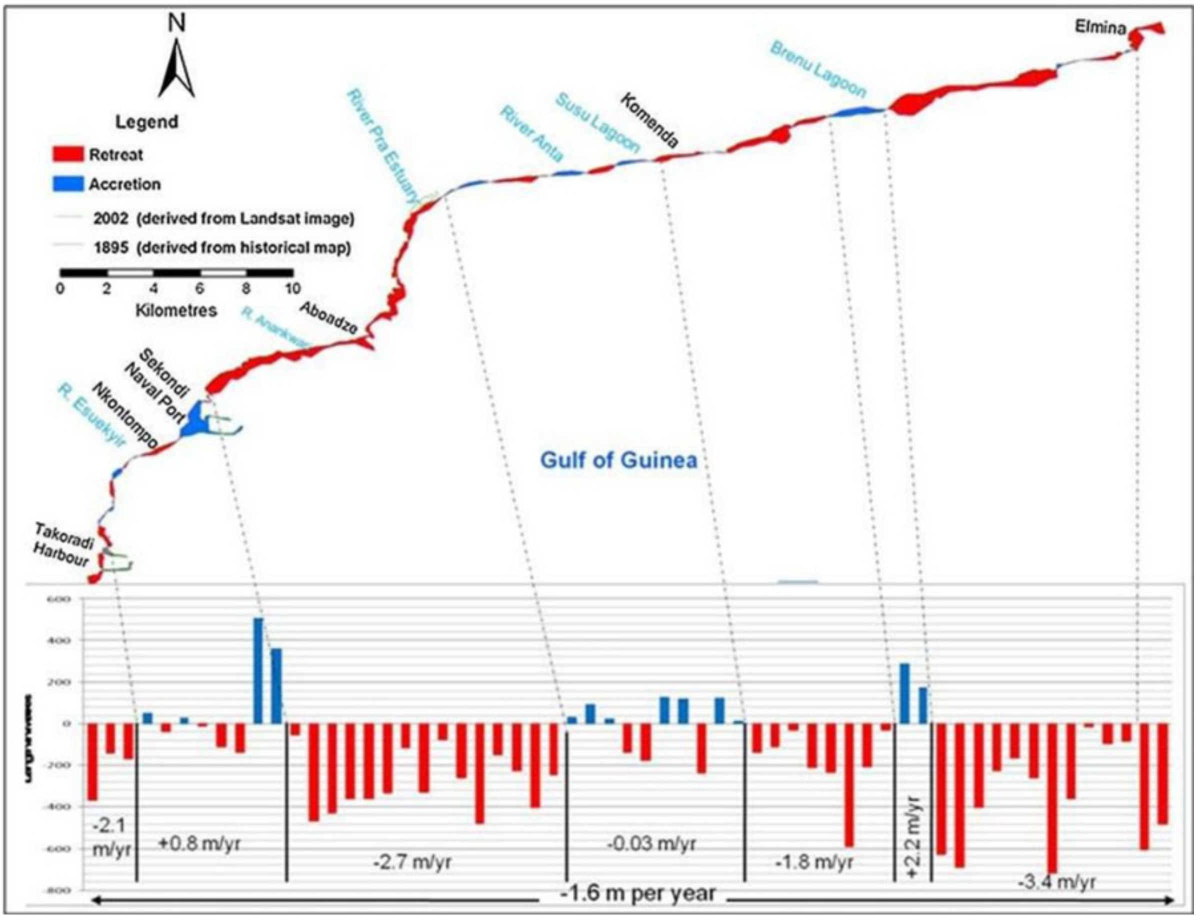
Coastal erosion is greatest in areas where sandy beaches are exposed to waves and lack a supply of incoming sediment. Areas around river mouths and barrier inlets are particularly dynamic and reactive to flooding events

(Coastal Resources Center, 2013). High energy waves on this open coast result in favourable conditions for coastal erosion (Appeaning Addo, Walkden and Mills, 2008). Despite coastal erosion being a natural phenomenon, its trends in Ghana have mainly been aggravated by human-induced factors such as beach sand mining or “winning” for building purposes (Boateng, 2012); (Jonah et al., 2015; Jonah et al., 2016), which is illegal. This issue is more severe on the east coast with shoreline retreat rates between 3.4 and 3.9 m per year (Boateng, 2012); (UNESCO-IOC, 2021).

Figure 26 shows the shoreline along STMA. According to Boateng, Isaac research there is an average land lost to the sea of 8.5 ha per year along this section of the coast. On shoreline change, the mean retreat rate over the period of assessment was 1.6 m, +/–0.4 m per year, with considerable variation along the coast. This rate varies by shoreline type and the direction of the coast. The study also revealed that, generally, the lagoon embayments were accreting, but the cliffs and headlands were retreating.

However, the accretion recorded at the Sekondi naval port area is artificial, because the area was reclaimed as part of the port development (Boateng, 2012) and continues to be maintained.

Figure 26 l Coastline change in the Western Region’s in southeast facing shore



Source: (Boateng, 2012)

The low retreat rate recorded between the two port jetties (Takoradi and Sekondi port jetties) seems to suggest that the defences are presently effective, Also the high recession rate between the down-drift of Sekondi naval port jetty and River Pra estuary might have been caused by the effects of the port jetties. The highest rate of retreat (3.4 m, +/– 0.4 m per year) was recorded in the area between Brenu lagoon and Elmina, followed by the area between Sekondi port jetty and Pra estuary (2.7 m, +/– 0.4 m per year). The area that recorded the highest natural accretion (2.2 m, +/– 0.4 m per year) within the case study area was around Brenu Lagoon inlet where beach tourism development has led to improved beach management and less beach mining (Boateng, 2012).

Through the Boateng, Isaac research, it was identified that interception of littoral sediment by port jetties, illegal beach mining and interception of littoral sediment by lagoon inlets are among the causes of erosion in this area (Boateng, 2012). Sea defences meant to protect the shoreline have failed in many locations, often due to their improvised nature or inadequate design and construction, or the fact that natural buffers such as mangroves or dunes have been removed. Infrastructure can be protected using engineered structures, but alternatives such as siting them away from risky areas to begin with or relocating them as part of managed retreat are strategies can be cost effective and should be considered (Coastal Resources Center, 2013). Alternative solutions such as sand nourishment could also be used.

Climate change and sea-level rise events are expected to increase in the coming years (IPCC, 2018). The persistent impact of sea-level rise, changes in the frequency and intensity of climate conditions and water infiltrating the soil will inevitably accelerate coastal erosion process. The pressure and weathering process on this sensitive environment will only intensify as contemporary coastal urbanisation, population growth and activities continue. Apart from the loss of valuable sensitive ecosystems, socio-economic implications will be severe, as key industries, major residential settlements, poorer tourism dependent communities, conservation sites, UNESCO heritage and historical monument are all located at less than 200 m from the shoreline of Ghana (Boateng, 2012); (UNESCO-IOC, 2021).

7.3 Flooding

As global warming expands the ocean's upper layer due to increases in temperature, coastal communities are expected to experience increasing coastal impacts of sea-level rise (IPCC, 2018). Coastal erosion and flooding in West Africa severely threaten people's communities, livelihoods, safety and investments. Stronger storms and rising seas are wiping out roads and buildings; some beaches are being deeply mined for sand, protective mangroves are deforested, and people are increasingly vulnerable to the impact of climate change. (The World Bank Group, 2019).

Coastal hazards are a major threat to the Western Region of Ghana. Consistent with global increases, sea-level rise in Ghana conforms with the world trend at a historical rate of 2 mm per year and an estimated average local subsidence rate of ≤ -1 mm per year (Boateng, Wiafe and Jayson-Quashigah, 2016). Ghana's coastal lowlands are expected to be impacted tremendously by rising sea-level as most barrier beaches are retreating at a rate of about 1 m per year in recent decades (Boateng, Wiafe & Jayson-Quashigah, 2016). The rising sea level will aggravate sea incursions resulting in overwash, coastal flooding, land loss, and shoreline retreat.

The coastal population is large and growing because of the booming oil and gas industry. The largest urban centres and much of the economic activity are located along the coast, so flooding and coastal erosion pose a threat to development and well-being in the region. Rapid and often unplanned urbanization and human-induced activities on the coast have devastated the natural landscape that once served as a buffer for erosion and flooding and placed humans and properties on the backshore in a more vulnerable position to future storms and sea-level rise. These developments disproportionately affect the poorest and most marginalized and will intensify due to climate change (UNESCO-IOC, 2021); (The World Bank Group, 2019).

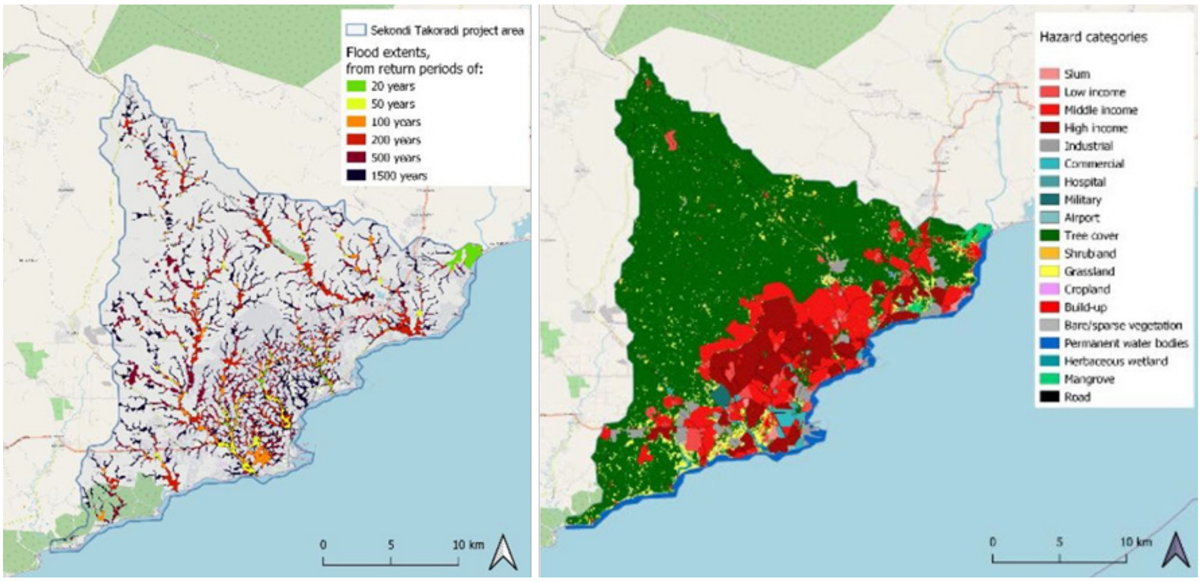
Efforts to protect coastal economic activities and settlements from coastal flooding and erosion are not new in the Western Region. Much of the Sekondi-Takoradi coast is armoured with shoreline protection methods ranging from seawalls and groins to make-shift solid waste rip-rap. Takoradi Port was built in the 1920s and includes a large breakwater to reduce wave impacts on ships and shore-side facilities.

A high-level assessment of the flood hazards, damage and risks in Sekondi-Takoradi using a flood risk mapping and modelling approach was done in 2022 to improve the evidence-based information on urban flooding, to support the planning and implementation of solutions to alleviate the flood risk. 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 combined flood hazard information for different return periods, land-use data, and flood damage curves for different land-use type (Figure 27). These were then combined to determine an Average Expected Damage (AED) function for Sekondi-Takoradi. The potential impact of climate change was determined by changing the expected recurrence intervals for the different flood events and deriving an updated AED based on the associated increasing flood risk.

Floods are dominated by two aspects: the presence of excessive water and 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 militating 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).

Sekondi-Takoradi suffers from flash floods and landslides due to steep nature of the city area. The main problems exacerbating the flood impact are people that build and live in flood prone areas of natural drains. Also, a number of drains are blocked or have insufficient capacity. Coastal floods are not a major issue yet, although there are flood problems caused by coastal erosion. This exacerbated by coastal storms/storm surges combined with urbanisation could potentially worsen the impacts of urban flooding (Triple Line Consulting Limited, 2022).

Figure 27 I Flood hazard and land-use maps for the Flood Risk Mapping and Modelling study.



Source: (Triple Line Consulting Limited, 2022)

In terms of adaptation, a drainage master plan for Sekondi-Takoradi was prepared in 2006. The master plan suggested a combination of drainage improvements and flood control measures as well as planning and contingency measures, both short and long term It also recognises the issue of the combination of high tides and storms and considered proposing flap gates and pumping to provide retention in the wetland areas at the mouths of the streams but found the cost to be unaffordable.

Generally, these wetland areas have not been developed, although there are some recreational buildings, so remain as flood storage during low tides. The plan has been partially implemented with main drains constructed. However, the drainage system's effectiveness has been reduced by urban development in low lying areas and also close to the coast, particularly in those areas intended to store, or attenuate, storm water, such as in Bakado and the Regional Hospital Extension. The latter is a good example of how development has infilled a low-lying area but has increased the flood risk around the junction on the STMA Road (Triple Line Consulting Limited, 2022).

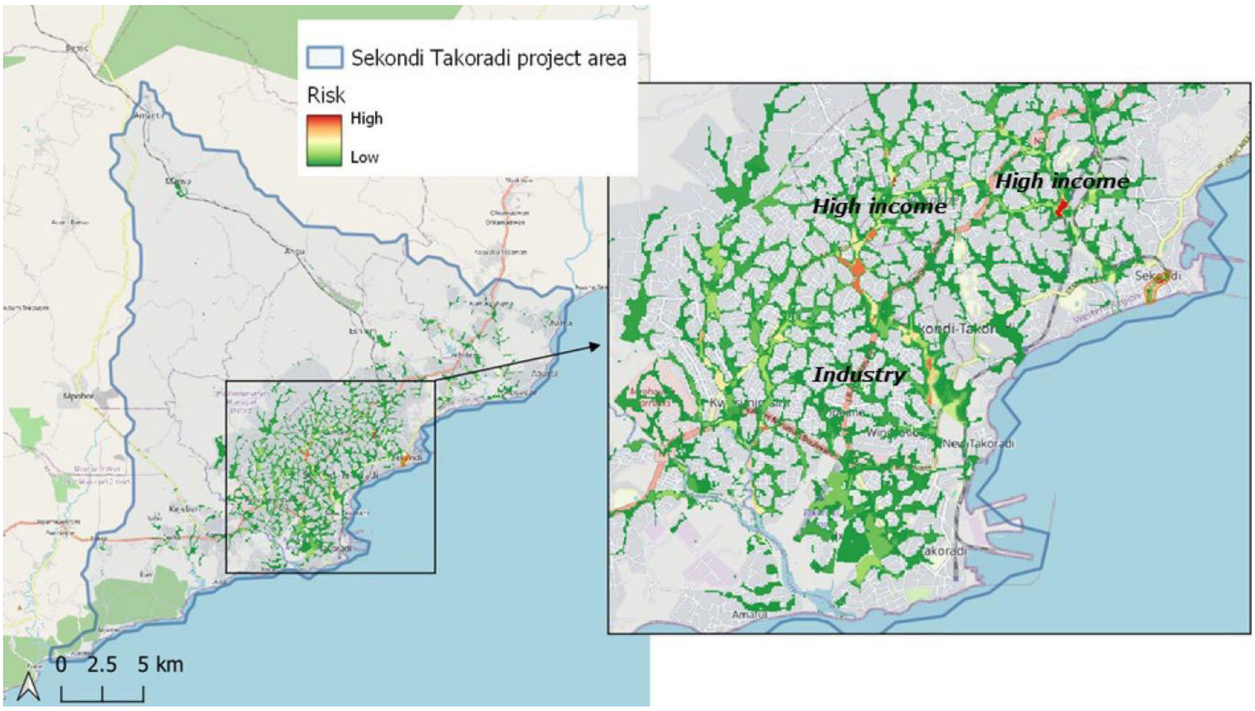
The maps below present the resulting flood hazard areas for Sekondi-Takoradi (Figure 28). From this it can be concluded that in Sekondi-Takoradi the risk from flooding is mainly confined to the southern part of the catchment where the denser urbanised area is. The northern part of the catchment seems to have little flood risk because it mostly consists of bush and some small, scattered villages.

Several high-risk areas in urban Sekondi-Takoradi can be identified (as highlighted in Figure 28 below):

- An industrial area in the central area
- High-income residential areas

These areas should be prioritised when developing flood mitigation measures, as they likely have a high-cost benefit ratio. It is also important to note that this flood hazard assessment is based primarily on an assessment of inland or urban flooding and does not account for the impacts of sea level rise.

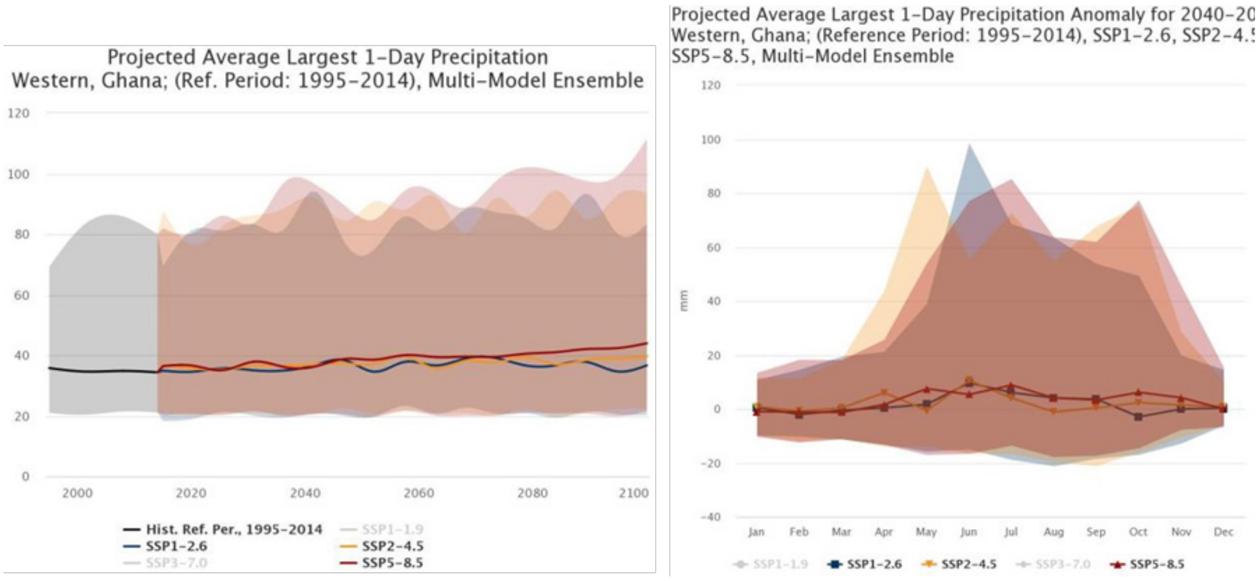
Figure 28 I Resultant flood risk map of Sekondi-Takoradi MA



Source: (Triple Line Consulting Limited, 2022)

The expected change in the maximum daily rainfall under the different global emission scenarios for the Western Region in Ghana from the CMIP6 ensemble is shown in (Figure 29) shows a significant increase under SSP3-7.0 and SSP5-8.5, but not under SSP2-4.5 and SSP1-2.5. The greatest impact is likely to be in July with the median values showing an increase of around 10% in the average maximum 1 day rainfall but with a range from -37% to +153% by mid-century (i.e. centred on 2050).

Figure 29 I Expected change in the Maximum Daily Rainfall for the Western 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 that the on average the current 1 in 10 year and 1 in 100-year events could become up to 1.72 and 2.3 times more likely under SSP5-8.5 by 2050. The worst-case scenario (i.e. 90th percentile under SSP5-85) indicates that the 1 in 100 year event (current AEP = 1%) could become up to five times more likely in any year by 2050. This indicates a significant increase in the risk associated with extreme rainfall events used for design purposes and flooding due to climate change.

Table 11 I Expected change in Annual Exceedance Probability for Design Rainfall events for the Western 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
SSP1-2.6	0.75	1.3	1.93	0.61	1.56	3.39
SSP2-4.5	0.84	1.45	2.53	0.72	1.99	4.13
SSP5-8.5	0.93	1.72	2.79	0.87	2.3	5.29

Source: Climate Change Knowledge Portal

7.4 Ecosystems

Sekondi-Takoradi is a relatively urbanized Metropolitan Area and because of development expansion, limited areas of natural vegetation remain. Much of the southern and coastal parts of the district are settled, while the northern area is primarily non-mono cocoa tree crop agriculture. Grasslands cover parts of the central and northern areas of the district (Ghana Forestry Commission, 2021).

Naturally forested areas are limited, however, the Monkey Hill Conservation Forest provides critical habitat for endangered and otherwise threatened species including Geoffroy's black and white colobus (*Colobus vellosus*), the White naped managabey (*Cercocebus atys lunulatus*), and Lowe's guenon (*Cercopithecus campbelli lowei*) (Horwich & Stevens, 2013). It also helps mitigate potential flood risks.

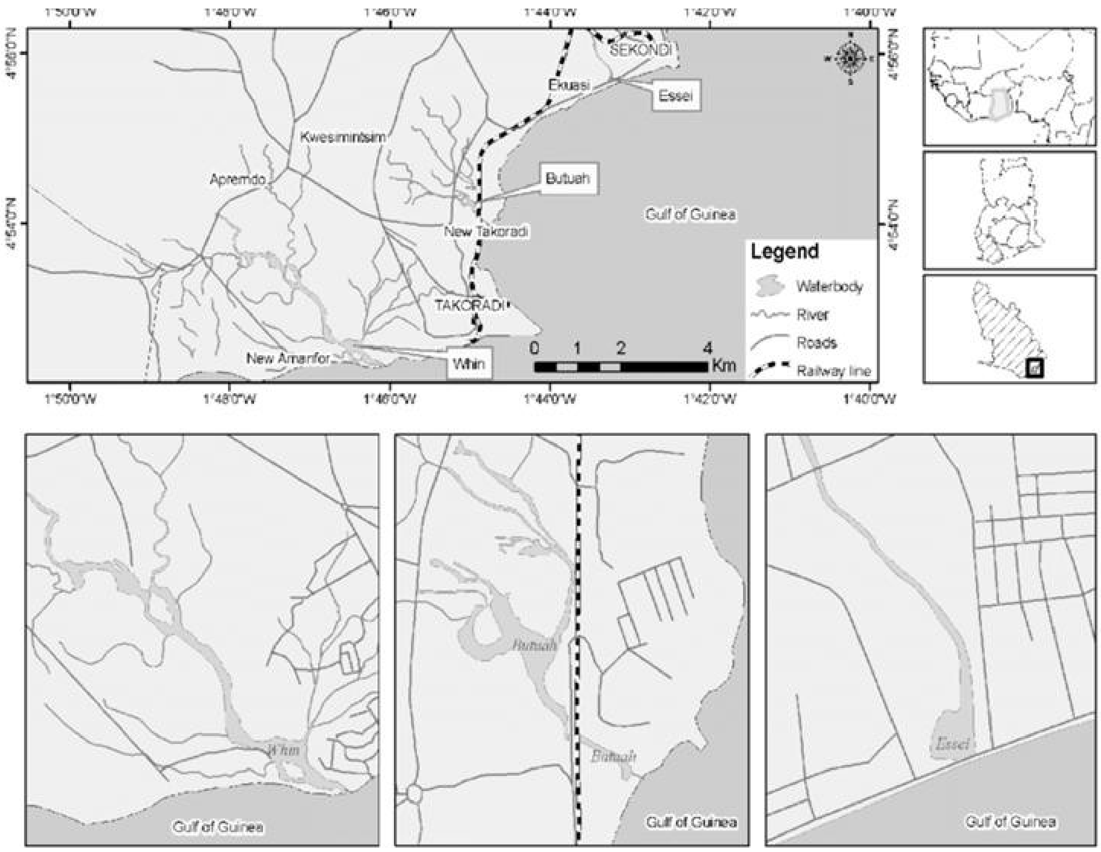
Encroachment represents a more acute threat to this existing natural forest area than changing climate, however changing climate conditions could threaten this and other forested areas through shifting climatic conditions and increase wildfire risk (high heat and drought conditions). Threats from pests and microbes also increase with climate change as new invasive species move into the area which can be particularly dangerous for forest stands already weakened by drought and wildfire (Graziosi, Tembo, Kuate, & Muchugi, 2020). Urban tree cover has become a priority in recent years with numerous efforts to plant trees both in reserves and in the metropolitan area, for example the Sekondi-Takoradi Metropolitan Assembly plan to plant 10 000 fruit trees throughout the twin cities (Siabi-Mensah, 2022).

In addition to providing habitat for birds and other species, urban tree coverage can reduce heat island effects and mitigate potential human health risks from extreme heat as well as reducing flooding risks.

Mangroves, including the Essei and Butua lagoons and the Whin River Estuary, are also at risk from encroachment, fill, illegal mining, and pollution. Nationwide, mangrove coverage fell by nearly half between 2006 and 2014 (Nunoo & Agyekumhene, 2022). Residents of Sekondi-Takoradi have reported awareness of depleting wetlands in recent years (Mattah, Futagbi, & Mattah, 2018) (Duguma, et al., 2022) Essei and Butua lagoons are comprised mainly of White mangroves (*Avicennia germinans*) while the Whin River Estuary also includes Red (*Rhizophora racemose*) and black (*Laguncularia racemose*) mangroves (Nunoo & Agyekumhene, 2022).

These areas provide important ecosystem services including habitat, particularly as a nursey and spawning ground for fish species important for nutrition and livelihoods, water filtration, flood protection, and materials provision (e.g., construction materials and fuelwood for smoking fish).

Figure 30 | Location of Essei and Butua Lagoons and Whin River Estuary



Source: Okyere (2011)

Mangroves are at risk from climate change due to a variety of factors, as described in Duguma et al. (2022):

- **Rising sea levels** affect salinity and flooding of mangroves, which affect growth and survival
- **Extreme storms** can destroy canopies and uproot mangroves in extreme circumstances
- **Reduced precipitation** can lead to soil salinity increases beyond ranges healthy for mangroves
- **Increased temperature** alters the ability of mangroves to store carbon dioxide and affects photosynthesis and evaporation rates.

Further erosion may occur from higher precipitation events leading to stronger river flow upstream.

In addition to the challenges development pressures place on mangroves, much of the population associates wetlands with mosquito breeding and therefore is less inclined to participate in conservation efforts (Dadzie-Paintsil & Mensah, 2022). As climate change may also increase vector borne disease risk, this likely will continue to be a challenge.

Marine ecosystems are also changing due to climate change due to rising temperatures, ocean acidification, and other effects. These are discussed below in the fisheries section.

7.5 Energy Security

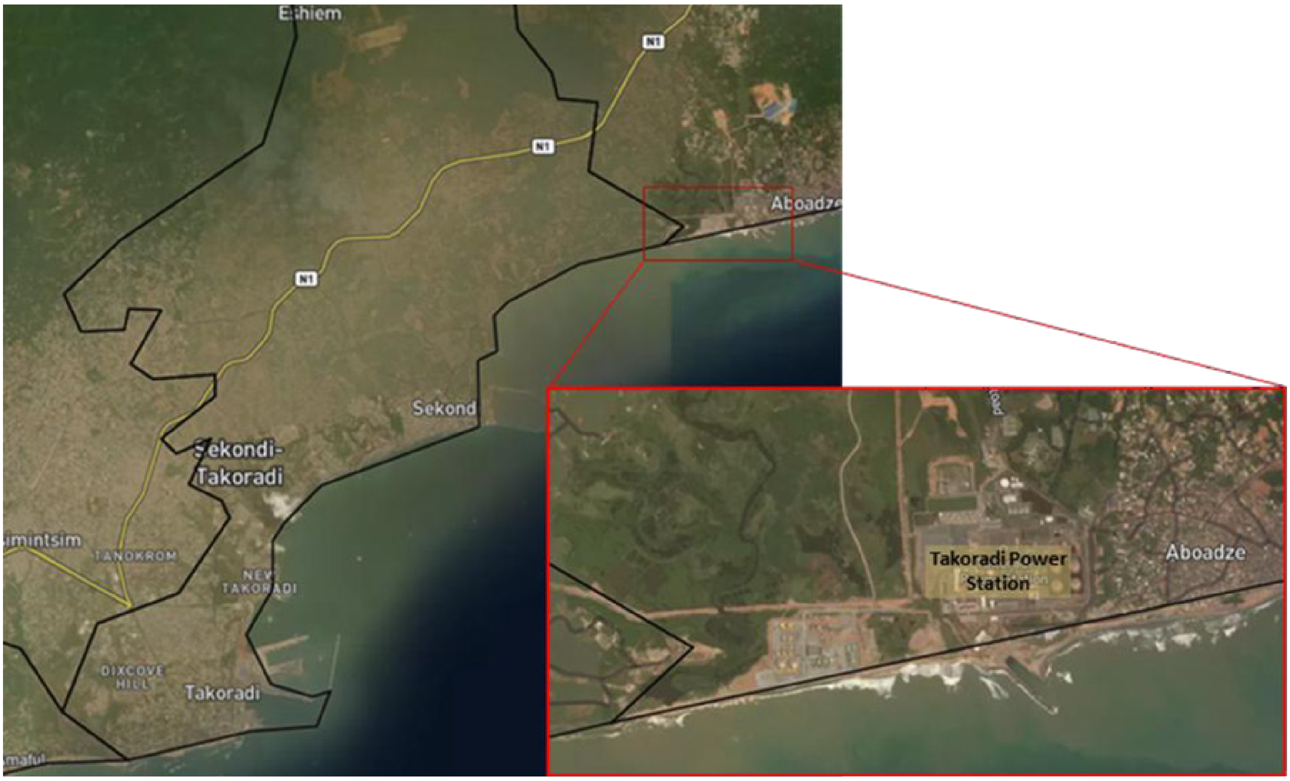
Climate change threatens the supply, demand, and reliability of energy, including both electricity and non-electric sources. Households in Sekondi-Takoradi have high levels of access to electricity—97 percent of urban households in the Western Region have access to electricity (Ghana Statistical Service, 2022a) but reliability remains an issue. Relatively frequent outages occur through the region, driven by transmission issues, low water levels in hydropower dams, and gas supply interruptions.

Recent expansions in thermal power have helped alleviate some of the power-supply driven challenges, however the electricity transmission and distribution infrastructure remain a critical vulnerability (Ackah, 2021). Access to other sources can be interrupted by extreme events.

Climate change threatens electricity reliability through increased risk of flooding of critical infrastructure (e.g., substations and power plants); transmission failure and pre-emptive shutdowns during high heat events and periods of high wildfire risk; reduced transmission capacity under warmer atmospheric conditions; and line damage during storms and high wind events.

- **Coastal flooding.** The Takoradi power station (which includes three plants) is at risk of coastal flooding (see proximity to the current shoreline in Figure 31). Although this plant is located just outside of the MMDA boundary, it is a critical to electricity security in Sekondi-Takoradi. The station has a combined size of 692 MW and the plants at risk of flooding serve over 325,000 people (Adshead, et al., 2022).

Figure 31 I Location of Takoradi Power Plant



Source: Image from Ghana Forestry Commission (2021)

- **Transmission failure and reduced capacity.** Climate change can also result in electricity system failures through extreme weather impacts on transmission and distribution lines (i.e., high temperatures, lightening, and wildfire), reduction in infrastructure lifespan due to weather, and reduced capacity during high heat events (Fant, et al., 2020). At least ten major grid interruptions nationwide in 2021 were caused by tripped transmission lines (Ackah, 2021).

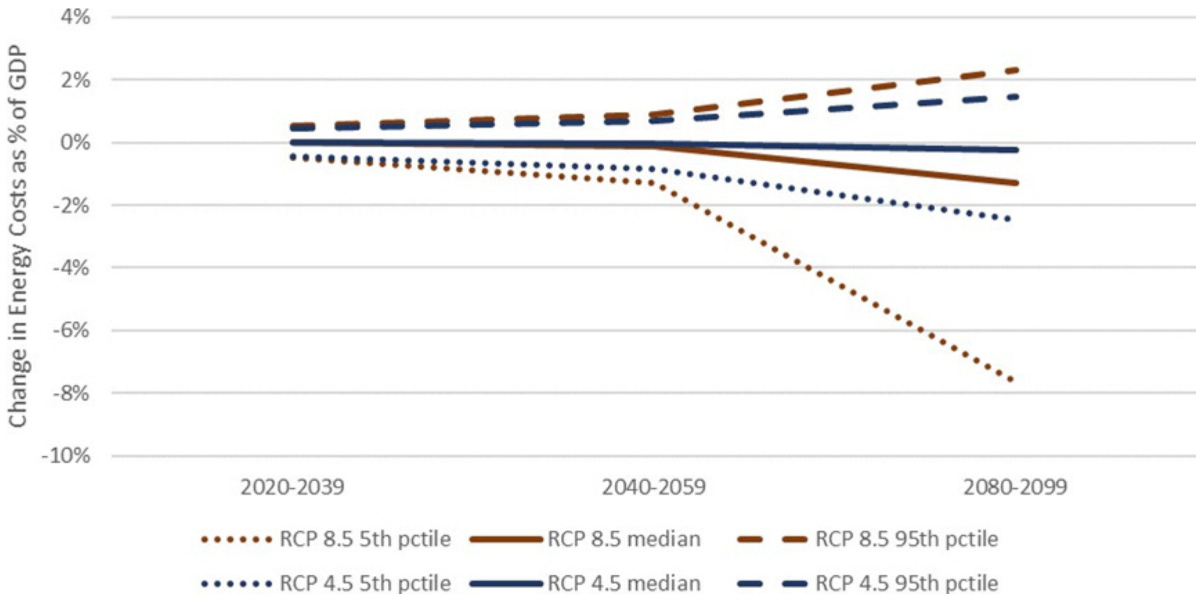
Electricity outages cause significant economic impacts as well as negative outcomes for human health and wellbeing. Household costs associated with adapting to an unreliable power source (e.g., generator purchase and usage) may exceed regular expenditures on energy. Food spoilage, damage to electronic appliances, loss of communication, risk of burglary, education disruptions, and reduction in household earnings during outages have also been reported as major concerns during power outages in Ghana (Nduhuura, Garschagen, & Zerga, 2021).

Women are particularly impacted by outages through the safety concerns in poorly lit spaces. Additionally, during prolonged outages, households may turn to alternative fuels such as firewood, the collection of which falls disproportionately on women and girls (Adshead, et al., 2022). Populations who rely on electricity-powered medical devices are also at heightened risk of negative health outcomes during outages.

These climate risks will be exacerbated as electricity demand grows due to increasing population, rising incomes and electricity access, and climate change-induced increased demand for air conditioning. Although current studies offer conflicting projections of how energy demand in Ghana will respond to warming temperatures, Sekondi-Takoradi is projected to experience minor increases in energy expenditures through early- to mid-century and a minor decrease by end of century. This is the net result of increasing electricity demand and decreasing demand for all other fuels.

Previous studies have found energy demand to increase in the region; the variation depends primarily on assumptions of air conditioning uptake (Diaz & Moore, 2017); (Anthoff & Tol, 2013).

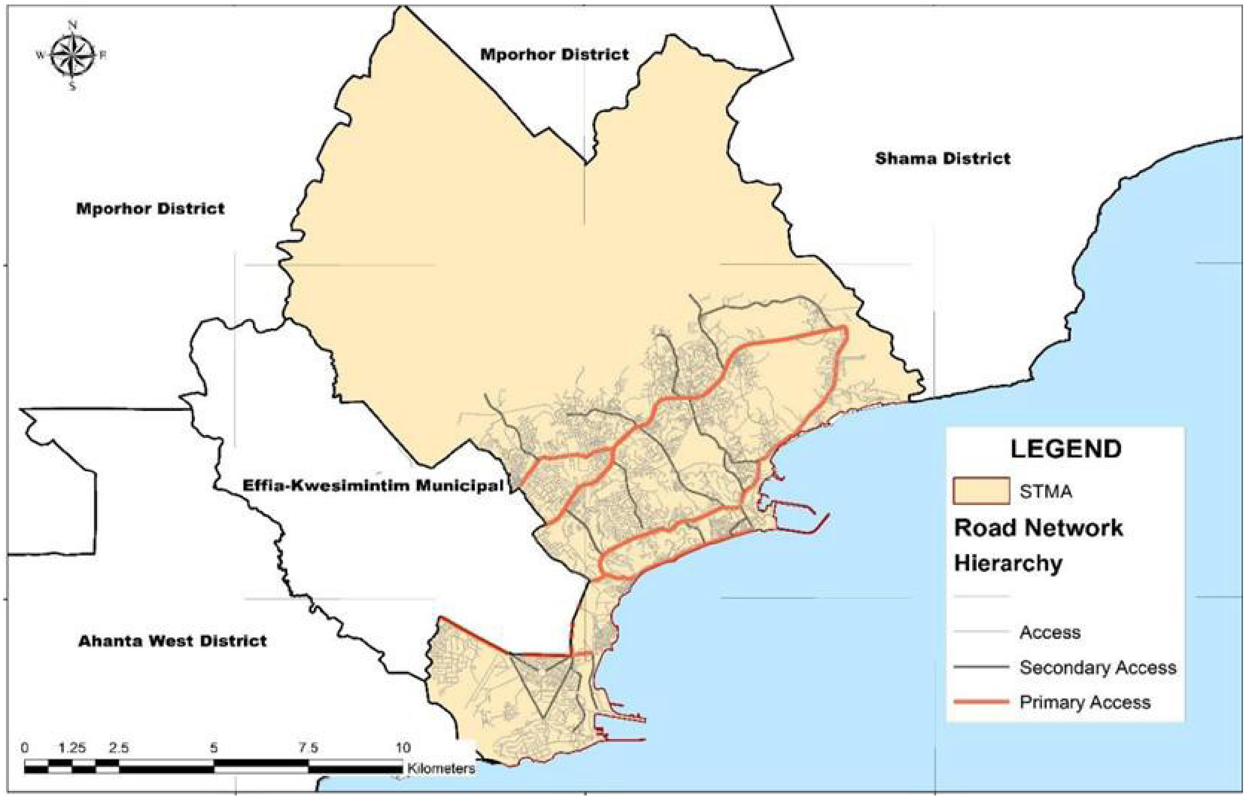
Figure 32 I Projected change in national energy expenditures (both electricity and other fuels) due to climate change as a percentage of projected GDP



7.6 Transport Systems

Sekondi-Takoradi's transport system, including its roadways, rails, airport, and port play crucial roles in facilitating the movement of people and goods within the city. The area's urban roadway network is around 899 km long, 42% of which includes paved roads (STMA, 2021). Figure 33 shows primary, secondary, and tertiary road infrastructure in the metropolitan area (STMA, 2021). This infrastructure has become particularly important following the area's oil exploration, which has led to an increase in traffic congestion (Fiave R. E., 2017). Rail within the area also helps connect the district to other major urban centres such as Kumasi and Accra (Adshead, et al., 2022). While these resources are vital to facilitating socio-economic development, climate stressors, including increased temperatures, precipitation, and flooding events have the potential to negatively impact transport infrastructure and make them vulnerable to degradation (Cervigni, Losos, Neumann, & Chinowsky, 2016).

Figure 33 | Sekondi-Takoradi Metropolitan Assembly Road Network



Source: STMA, 2021

Specifically, an increase in temperature could have important impacts to paved road infrastructure by accelerating the degradation of binding materials making the infrastructure less suitable for travel (Cervigni, Losos, Neumann, & Chinowsky, 2016). This could have important implications to road networks such as the Trans West African Highway, as Western Ghana is expected to experience an average of 1.75°C of warming under SSP2.4-5 (World Bank, 2021; (Ghana Highway Authority, 2023). Moreover, this warming could exacerbate existing degradation to arterial roads that occurs from the high volume of cargo traffic moving to and from the district's harbour (Fiave R. E., 2017).

Changes in precipitation could also have negative impacts on both paved and unpaved roads by reducing the carrying capacity of the infrastructure and washing away road networks (Cervigni, Losos, Neumann, & Chinowsky, 2016). Paved and unpaved roads are also vulnerable to inland flooding events which can wash away infrastructure and lead to the overtopping of roads (Cervigni, Losos, Neumann, & Chinowsky, 2016). This is particularly important in the Sekondi-Takoradi area which may be vulnerable to inland flooding hazards in the future (World Bank, 2021). Railways within the country have also been identified as vulnerable to damages from inland flooding events, specifically, the Western rail line which runs from Manso to the Takoradi Port (Adshead, et al., 2022).

Overall, damage to transport infrastructure can increase traffic congestion and have other important socio-economic impacts (Cervigni, Losos, Neumann, & Chinowsky, 2016). Research by Twerefou et al. suggests that by 2100, damages to road infrastructure due to climate change could result in costs ranging from $4.7 million to $6.8 million for the country depending on adaptation responses (Twerefou, Chinowsky, Adjei-Mantey, & Strzepek, 2015). Additionally, an estimated 430,000 individuals could lose access to health care in the district due to the flooding of road networks (Adshead, et al., 2022).

The Takoradi International airport has also been identified as being vulnerable to flooding risks, which could disrupt the estimated 113,000 annual passenger trips the airport supports (Adshead, et al., 2022). Damage to this infrastructure could also limit prospects for female empowerment by hindering employment opportunities for women (Adshead, et al., 2022).

Table 12 I Summary Description of Impacts of Climate Change on Roads

Road type	Climate stressor	Effect
Paved roads	Temperature	Increased temperature leads to accelerated aging of binder
		Increased temperature leads to rutting (of asphalt), and bleeding and flushing (of seals)
	Precipitation	Increased precipitation leads to increased average moisture in subgrade layers and reduced load-carrying capacity
	Flooding (in excess of design flood)	Washaways and overtopping of road
Unpaved roads	Temperature	No effect
	Precipitation	Increased precipitation leads to increased roughness of the road surface, increased average moisture content in subgrade layers, and reduced load-carrying capacity
	Flooding (in excess of design flood)	Washaways and overtopping of road

Source: Cervigni et al., 2016

7.7 Fisheries

The fishing sector plays an important role in economic development and food security in the country. In 2015, it was estimated that the fisheries sector produced $1 billion in revenue and contributed around 4.5% to national GDP (Republic of Ghana Ministry of Fisheries and Aquaculture Development, 2015). While employment in the industry is dominated by men, the sector has created opportunities for female empowerment with women taking on roles in fish processing and trading (Stanturf, et al., 2011); (Hasselberg, et al., 2020). Over time, the share of employment reliant on the fishing industry has increased and in 2015 around 10% of the country's population was supported by the sector (Republic of Ghana, 2015).

In Sekondi-Takoradi, around 5% of the working population is involved in the agricultural, forestry, or fishery industries (Ghana Statistical Service, 2022b). As it relates to food security, 60% of animal protein eaten in Ghana is provided by fish, thus contributing to nutrient availability within Ghanian diets (Republic of Ghana Ministry of Fisheries and Aquaculture Development, 2015); (Hasselberg, et al., 2020). Recent public discourse and policy has focused on non-climatic threats to the sector such as pollution from the oil and gas industry, overfishing, and eutrophication (Tanner, et al., 2014); (Republic of Ghana Ministry of Fisheries and Aquaculture Development, 2015).

Oil exploration started in 2007, and the area began producing approximately 108,000 barrels of crude oil per day soon after (Fiave R. E., 2017). However, local fishermen have expressed concern over offshore oil installations and zones of exclusion in marine areas that encroach on productive fishing areas (Ovadia & Graham, 2022). In response, the country's 2015 Fisheries Management Plan outlined goals to create marine protected areas to limit impacts to fish nurseries and breeding grounds from oil installations (Republic of Ghana Ministry of Fisheries and Aquaculture Development, 2015). The industry, however, continues to be threatened by additional stressors including those from climate change which have the potential to threaten fishing ecosystems, stocks, and livelihoods.

Catches from marine fishing contribute the largest share of Ghana's total catch, as around 70% of landings come from marine sources (Doku, Chen, Alhassan, Abdullateef, & Rahman, 2018). However, coastal lagoons and mangroves also play a role in supporting fish catches for subsistence-based fishers and the commercial fishing industry (Finegold, Gordon, Mills, Curtis, & Pulis, 2010). These ecosystems are threatened by climatic stressors including sea level rise, coastal erosion, and extreme weather events which can cause damage to fish shelters and breeding grounds (Tanner, et al., 2014).

By 2100, sea levels near Sekondi-Takoradi are expected to rise by approximately 0.4 meters relative to historical sea levels under RCP 4.5, which will threaten coastal habitats and exacerbate coastal erosion (World Bank, 2021). Such climatic stressors could put pressure on lagoon ecosystems such as the Anankwar Lagoon in Sekondi-Takoradi which is a key area that supports fishing by the Essipon Community, and already experiences threats from coastal erosion (Finegold, Gordon, Mills, Curtis, & Pulis, 2010); (Mensah, Koranteng, Bortey, & Yeboah, 2006)

Changes in sea-temperature and wind patterns can also have negative impacts on ecosystem productivity and species abundance. Marine productivity in the country is sustained by the Central West African Upwelling system (Finegold, Gordon, Mills, Curtis, & Pulis, 2010). Ghana's most productive fishing seasons coincide with upwelling seasons that occur from July – September and December – February, which help support small pelagic and demersal species (Hasselberg, et al., 2020). However, potential changes in surface sea temperature and wind circulation patterns from climate change could potentially disrupt water stratification processes and upwelling events, potentially making marine waters less productive (Tanner, et al., 2014). Changes in surface sea temperature could also impact important catch species in the country such as anchovy, mackerel, sardinella, tuna, and billfish. Specifically, rising surface sea temperatures could lead to a decrease in sardinella abundance, while also contributing to an increase in anchovy abundance (Tanner, et al., 2014).

Climate change may also disrupt the livelihoods of fishers by damaging equipment and creating unsafe conditions. Marine fishing in the country is dominated by small artisanal fishers who rely on small to midsized canoes (Stanturf, et al., 2011). However, projected increases in storms and coastal waves could damage these vessels, landing sites, and create more dangerous conditions for fishers (The World Bank Group, 2021c); (Freduah, Fidelman, & Smith, 2017). This could have important implications in Sekondi-Takoradi at the Albert Bosomtwi-Sam Fishing Harbour which already makes use of a 200-meter breakwater to protect against coastal degradation (Adom, Appiah, & Yarney, 2019). There is also the potential that existing port facilities will become more isolated as the coastline retreats around them.

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 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 climates 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 Then the main indicators should 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 plan for adaptation considering the uncertainty of future climate.

The two climate risk narratives were developed for Sekondi-Takoradi Metropolitan Assembly 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, and after stakeholder engagements.

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

Figure 34 | Increasing water security and drought risks for Sekondi-Takoradi Metropolitan Assembly

STMA Climate in 2053: Warmer and Drier

The residents of Sekondi-Takoradi Metropolitan Assembly, a coastal city in southern Ghana, reflect on life in the late 21st century, when early summer temperatures had only risen by a mere 1°C compared to the early 21st century. Back then, the effects of climate change were just beginning to manifest, and the city's inhabitants were yet to face the full extent of the challenges that lay ahead.

The year is now 2053, and Sekondi-Takoradi's people have endured decades of rapidly changing climate. Extreme climatic events like sea-level rise, flooding, and extreme heat have become more common, disrupting their daily lives. The once-thriving metropolis now grapples with escalating risks of infrastructural damage, loss of livelihoods, and community displacement and migration, with the most vulnerable groups, such as women and the elderly, bearing the brunt of these impacts.

Despite global efforts to mitigate climate impacts, temperatures in Sekondi-Takoradi have risen by around 1.5°C and mean annual precipitation has decreased by around 5%. The rising sea levels continue to exacerbate coastal impacts through coastal erosion, affecting various sectors such as fisheries, water resources, critical infrastructure, coastal ecosystems, health, and dry-land agriculture.

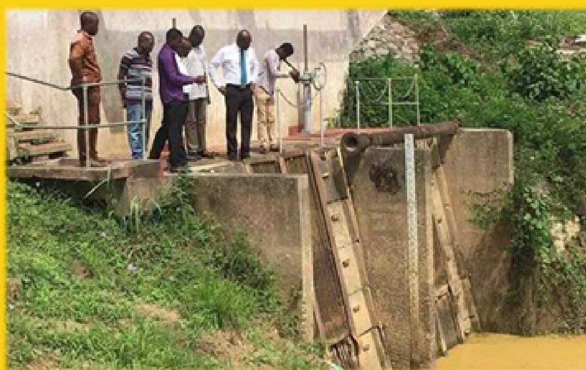
In a significantly dryer climate, water shortages have hit the local population hard, especially women and girls who shoulder the burden of fetching water for their families. It also impacts energy supply. Reduced rainfall and increased evapotranspiration, worsened by catchment degradation, sedimentation, and illegal sandmining, have led to even scarcer water resources. The decline in agricultural productivity in the region has compelled people to abandon their homes in search of better opportunities.

Health issues have also become more prevalent as warmer and drier conditions lead to a rise in heat-related illnesses like heatstroke and dehydration, particularly among vulnerable groups. While these are not as intense as inland, coastal communities grapple with mental health challenges due to displacement and loss of livelihoods caused by flooding, erosion, and landslides. Water scarcity has heightened the risk of water-borne diseases, especially in areas without access to essential services.

Sekondi-Takoradi's vulnerability to climate change is amplified by its proximity to the sea, reliance on coastal resources, and extensive coastal and environmental degradation, including the loss of coastal mangroves. In response, the city has embraced climate and gender-sensitive, nature-based solutions. These initiatives aim to reduce the sensitivity of key economic sectors to climate risk and boost communities' adaptive capacity while prioritizing the needs of women and other vulnerable groups.

As the city looks ahead to 2100, Sekondi-Takoradi municipality remains steadfast in its commitment to protect and empower its people in the face of an uncertain future. The community is united in their determination to build resilience and ensure that everyone, regardless of age, gender, or socio-economic background, has the support and resources needed to thrive in a rapidly changing world.

The protection of critical infrastructure located on the coast and managing of coastal retreat in highly vulnerable areas has become a priority with rising sea levels. This also requires efforts to protect coastal resources as mangroves that have been affected by the pollution caused by the oil industry.



Source: https://www.kyfilla.com/acute-water-shortage-hits-sekondi-takoradi/

Figure 35 I Climate Risk Narrative for STMA: Narrative 1 – Warmer and Drier

Climate Risk Narrative 1
Sekondi-Takoradi Metropolitan Assembly

Climate Zone: **Coastal**

Warmer & Drier

by 2053

RCP 4.5

45%

likelihood

Average annual temperature will **increase**: +4% (~1.3°C)

There is chance of **decrease** in mean annual precipitation: -5%

There is a chance for **increase** in dry spells and in number of hot days: +321% (~5 days)

There is a chance for **decrease** in extreme rainfall events: **-40%**

Increase in sea level rise: +0.4m

Potential Impacts

Infrastructure
Economic and social disruptions due to critical infrastructural failure because of coastal erosion.

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.

Fisheries
Decline in fish population due increased temperature and changes in sea water's PH level and reduced flow to estuaries and rivers.

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.

Coastal ecosystems
Loss of mangrove forests, wetlands, and coral reefs due to sea-level rise erosion, inundation of coastal ecosystems, increasing temperature and acidification.

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

Migration
High rates of migration due to drought, water scarcity and changes in livelihoods.

Energy Security
Failure to meet energy demand during heatwaves and hot days due to reduced hydropower output and damage to energy infrastructure that is in close proximity to the sea due to storm surges and coastal erosion, causing power outages and disruptions in the energy supply chain.

No- or Low-Regret Adaptation Measures

Infrastructure Sector	Water Sector	Fisheries Sector	Health Sector
1) Adaptive management practices. 2) Implement nature-based solutions and green infrastructure as protection of the coastal infrastructure. 3) Develop and strengthen early warning systems. 4) Implement coastal protection solutions for roads, ports, power stations and historical sites.	1) Improved access to secure water sources and water supply system. 2) Water supply resilience through regional harvesting and storage solutions and improved Integrated Water Resources Management. 3) Climate adaptation alignment across water sector institutions and planning mechanisms to ensure integrated water resources and catchment management. 4) Proactive risk-informed asset management of infrastructure. 5) Protection of water supply sources and infrastructure from sea level rise and coastal erosion.	1) Build seawalls, breakwaters, and other physical structures can help protect fishery infrastructure from sea level rise, storm surges, and other extreme weather events. 2) Implement ecosystem-based or nature-based solutions, such as mangrove restoration. 3) Develop and strengthen early warning systems for coastal storms.	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 36 I Increased coastal and urban flooding risks for Sekondi-Takoradi

STMA Climate in 2053: Hotter and Wetter

The year is 2053, the bustling coastal city of Sekondi-Takoradi in Ghana faces the grim reality of a changing climate. With average temperatures soaring by 2°C, frequent torrential downpours, and encroaching sea levels, the city's infrastructure and livelihoods are increasingly threatened.

At the heart of the city, we follow the story of Ama, a strong-willed fisherwoman who is struggling to maintain her livelihood amid a decline in fish production and loss of revenue from the fishery industry. As a single mother, Ama is disproportionately affected by the climate crisis. The burden of managing her household, providing for her children, and ensuring their safety in a rapidly changing environment weighs heavily upon her. As a result, her health is beginning to suffer leading to further challenges.

Ama's days are filled with long hours of fishing, followed by managing the household chores, preparing meals, and caring for her children. The increased frequency and intensity of storms make it harder for her to secure a stable income, while the loss of coastal ecosystems affects the availability of fish. The added stress of declining fish stocks exacerbates the gender inequality in her community, as women like Ama struggle to maintain their traditional roles in the face of environmental upheaval.

In addition to the economic challenges, Ama is increasingly concerned about her children's health as the risk of vector and water-borne diseases, such as malaria and dengue fever, increases due to warmer temperatures and the presence of stagnant water. As a mother, Ama bears the additional responsibility of caring for her sick children, further straining her already limited resources.

Meanwhile, Kofi, an engineer working at the nearby coastal power plant, faces the constant threat of storm surges that could damage critical infrastructure, disrupt energy supply chains, and displace communities. Kofi is part of a team tasked with finding innovative solutions to protect the city's vital installations and prevent widespread power outages and damage to critical infrastructure.

As climate risks escalate, the people of Sekondi-Takoradi find themselves uniting to confront the mounting challenges. At the forefront of this movement is Mayor Adwoa Mensah, an unwavering advocate for climate action and resilience. She inspires her community, rallying a diverse coalition of individuals, including Ama and Kofi to join forces with Mayor Mensah to form a community task force dedicated to tackling these pressing issues. They recognize the need for climate and gender-sensitive, nature-based solutions that prioritize the needs of women and other vulnerable groups and are determined to convince the government that protecting natural systems and providing support for vulnerable communities is essential. In their quest for a more resilient city, the task force members, led by Mayor Mensah, work closely with local authorities and international organizations to implement adaptive strategies. They advocate for the improvement of drainage systems, the development of sustainable infrastructure, and the implementation of land use policies that take climate risks into account. Under Mayor Mensah's guidance, the task force also champions women's empowerment and supports initiatives that help women like Ama and her family adapt to the challenges of climate change. Through their collaborative efforts, Mayor Mensah and the task force work tirelessly to lead Sekondi-Takoradi into a more climate-resilient future.

Through Mayor Mensah, Ama and Kofi's eyes, we witness the struggle and determination of a city to adapt to the new climate reality. Their story becomes a testament to the power of unity, innovation, and resilience in the face of overwhelming challenges while highlighting women's unique and disproportionate burdens amidst the climate crisis.

As Sekondi-Takoradi's future hangs in the balance, will the city be able to overcome the stormy days ahead, or will it succumb to the relentless forces of climate change? The fate of women like Ama rests on finding solutions that address all residents' needs as they navigate the uncharted waters of a changing world.

https://www.ghanaweb.com/ https://newsghana.com.gh/

Figure 37 I Climate Risk Narrative for STMA: Narrative 2 – Hotter and Wetter

Climate Risk Narrative 2

Sekondi-Takoradi Metropolitan Assembly

Hotter & Wetter

Climate Zone: **Coastal**

by 2053

RCP 8.5

30% likelihood

- Average annual temperature will **increase**: +6% (~1.65°C)
- There is chance of **increase** in mean annual precipitation: +8%
- There is a chance for **increase** in number of hot days: +487% (~7 days)
- There is chance of **increase** in extreme rainfall events: +101%
- **Increase** in sea level rise: +0.4m

Potential Impacts

Infrastructure

Economic and social disruptions due to critical infrastructural failure because of coastal erosion and flooding

Water security

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

Fisheries

Decline in fish population due more frequent and severe flooding, causing damage to coastal infrastructure and coastal habitats and loss of the coastal ecosystems

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

Coastal ecosystems

Loss of mangrove forests, wetlands, and coral reefs due to sea-level rise coastal flooding and erosion, inundation of coastal ecosystems, increasing temperature and acidification

Livelihoods

Loss of livelihoods leading to food insecurity and economic hardship for communities in Sekondi-Takoradi

Migration

High rates of migration due to sea level rise coastal flooding and erosion and changes of livelihoods

Energy Security

Damage to energy infrastructure that is in close proximity to the sea due to storm surges, extreme rainfall, flooding and coastal erosion, causing power outages and disruptions in the energy supply chain.

No- or Low-Regret Adaptation Measures

Infrastructure Sector	Water Sector	Fisheries Sector	Health Sector
1) Adaptive management practices. 2) Implement nature-based solutions and green infrastructure as measures for protection of the infrastructure. 3) Increase resilience of infrastructure by elevating structures, strengthening foundations, and adding barriers to protect the infrastructure against sea level rise, storm surge, and floods. 4) Implement redundant or backup systems, such as power generators and alternative routes for transportation. 5) Develop and strengthen the early warning systems.	1) Water supply resilience through investing in Nature-Based Solutions to reduce both increasing flood risk and water security. 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 and catchment management. 5) Proactive risk-informed asset management of infrastructure. 6) Protection of water supply infrastructure from, flooding, sea level rise, and coastal erosion.	1) Build seawalls, breakwaters, and other physical structures can help protect fishery infrastructure from sea level rise, storm surges, and other extreme weather events. 2) Implement ecosystem-based or nature-based solutions, such as mangrove restoration. 3) Develop and strengthen the early warning systems for coastal storms.	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

Due to its location, Sekondi-Takoradi is experiencing an increase in the frequency and intensity of extreme climatic events — particularly sea level rise, flooding, extreme heat, and changes in precipitation patterns. The climate analysis and baseline research (presented in previous chapters) revealed that current climatic events are likely to increase into the future.

Through a multi-stakeholder workshop, the climate hazards most common to the Sekondi-Takoradi MA were identified and validated by engaging with stakeholders to determine climate related hazards through their perceptions, knowledge, and personal experiences. Table 13 presents the top climate hazards identified by the stakeholders as the main hazards that pose climate-related risks to the livelihoods and lives of the communities under current conditions for Sekondi-Takoradi.

Table 13 I Climate change hazards identified during the Sekondi-Takoradi stakeholder workshop

Systems and Assets Exposed to Hazard	Climate Hazard	Climate risk and potential impacts
Fishery Industries	Changes in sea temperatures and acidification	The changes in temperature and PH level of the sea cause significant changes in the composition of fish populations, affecting the livelihoods of fishermen and the availability of seafood. The ocean's acidity can make it harder for some marine animals to build their protective shells or skeletons. The ocean's PH level can then impact the food chain and the economic viability of the fishery industries. Stakeholder's reported increase of alien species.
	Sea Level rise	The sea level rise may lead to the loss of coastal habitats such as wetlands and estuaries, reduce fish populations, and impact the economic viability of fishery industries. The wetlands and estuaries can be inundated, losing essential spawning and nursery areas for fish and other marine species.
	Extreme climate events	Extreme weather events, such as hurricanes, typhoons, and storms, can damage fishing infrastructure, affect coastal communities (safety) and disrupt fishing activities for extended periods
	Variable rainfall	Fishing patterns have changed, for instance, the Shama fishing industry has collapsed. Fishermen used to fish in wetlands or other areas which are now dry.

Water Supply	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 using both local sources and regional water sources.
Critical infrastructure	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.
	Sea Level rise	Sea level rise will cause coastal flooding, storm surges, high tides and coastal erosion and all these hazards will damage infrastructure and disrupt operations and business activities. During stakeholder's engagements communities reported that some coastal roads that used to only occasionally (seasonally) be flooded and are now flooded daily at high tide. • The Ghana gas pipeline is exposed in some areas due to coastal erosion. • Many reports of beaches, houses and communities that have been washed away. The increased sea-level heights impede drainage system as there is more backwash.
	Flooding	Increased coastal flooding can damage critical infrastructure such as roads, bridges, gas pipelines and buildings, disrupting transportation and business activities. Floods can also cause inundation of beach areas and ecosystems, landslides, and erosion, rendering roads impassable and difficult to access.
	Storms	Storm surges can damage or destroy roads, bridges, and other critical infrastructure along the coast, causing disruptions to business activities, transportation and 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, water logging, drought, extreme heat, and storms. Potential change in crop suitability.
	Changing precipitation patterns (more frequent dry spells and floods)	Heavy precipitation and increased frequency of floods can cause waterlogging and damage crops while dry spells and prolonged drought lead to water shortage and crop failure

	Storms	Increased number of storms and lead to crop failure.
	Pests	Increasing temperatures and precipitation (i.e., more flooding) are likely to increase the risk of infestation of pest and diseases leading to crop failure and reduced livestock production.
	Hotter Temperatures	Increasing temperatures and precipitation (i.e., more flooding) are likely to increase the risk of infestation of pest and diseases leading to crop failure and reduced livestock production.
Health systems	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 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.
Coastal Ecosystems	Sea Level rise	Sea level rise will cause coastal flooding, inundation of coastal habitats, saltwater intrusion, and changes in species distribution.

8.3 Impact Chain Analysis for Critical Systems and Assets

Sekondi-Takoradi, like many coastal cities, is vulnerable to the impacts of climate change.

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

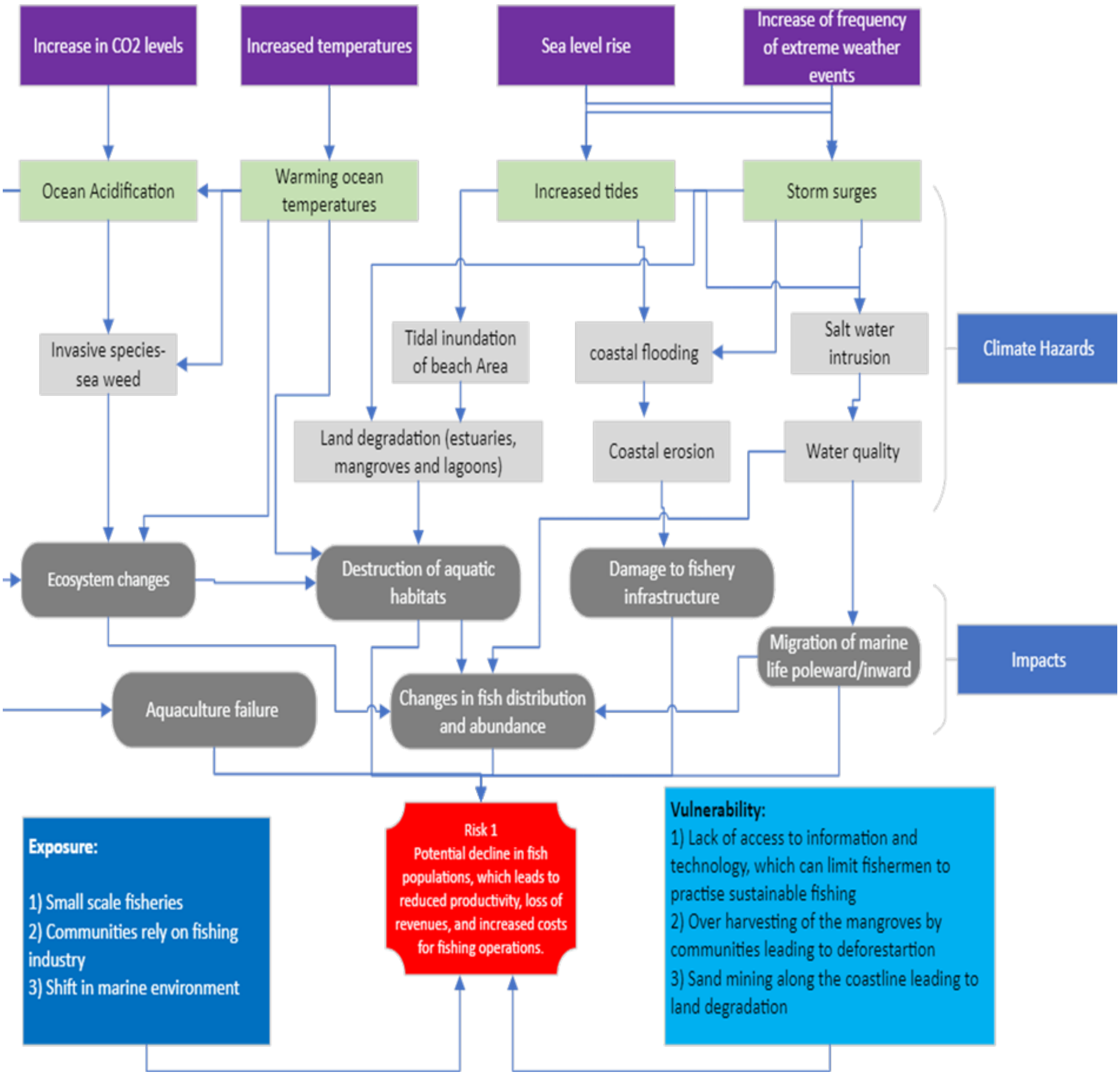
- Risk 1: Fisheries Impacts - Potential decline in fish population and increasing costs.
- Risk 2: Economic and social disruptions due to critical infrastructural failure.
- Risk 3: Community health: Increase in spread of disease and loss of life.
- Risk 4: Decline in coastal ecosystems.
- Risk 5: Loss of livelihoods.
- Risk 6: Water security.

8.3.1 Risk 1: Fishery- Potential decline in fish population

Overfishing and Illegal fishing have been major challenges threatening the productivity, profitability, and sustainability of the fishery industry in Ghana. Capital-intensive industrialized fishing, often by foreign fishing boats, has disrupted the social and economic organisation of local fishers, compromising the roles and status of women and undermining the viability of small-scale fishers (Ayilu, Fabinyi, Barclay, & Bawa, 2023), Climate change impacts are further exacerbating the existing challenges by modifying the coastal habitats and changing the distribution and production of fish populations. The fishery sector is also susceptible to climate stressors such as increased temperature, changes in sea waters' pH level, sea level rise, and extreme weather events.

Sea level rise will likely result in more frequent and severe flooding, causing damage to coastal infrastructure and coastal habitats and loss of the coastal ecosystems, which are all crucial for the fisheries industry. The climate change impact chains for the fisheries industry are shown in Figure 38.

Figure 38 I Fishery Impact Chain Diagram

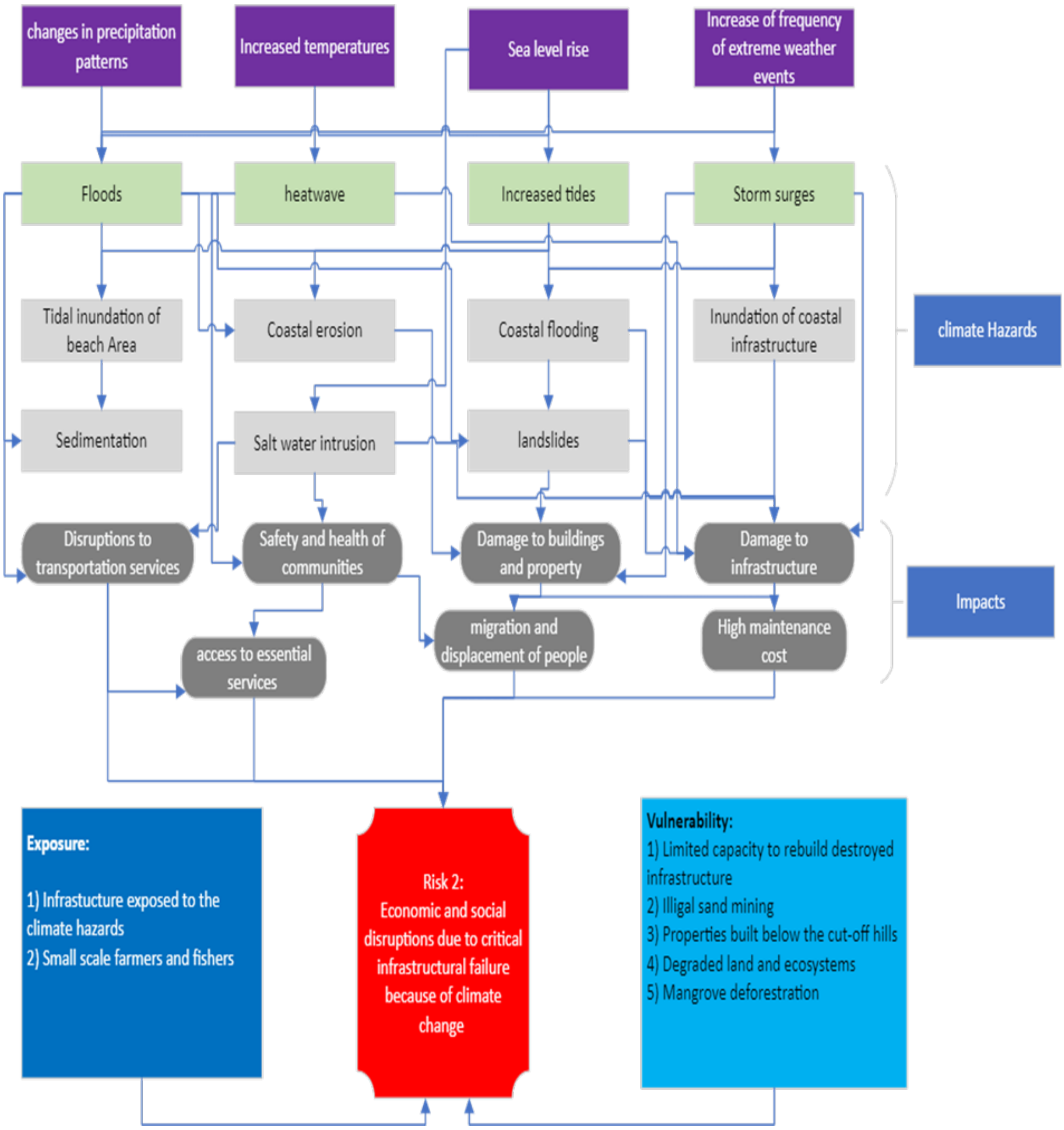


8.3.2 Risk 2: Economic and social disruptions due to critical infrastructural failure because of climate change

Climate hazards such as sea-level rise, storm surges, flooding, and erosion threaten Sekondi-Takoradi's critical infrastructure, primarily in the form of inundation and destruction of energy, transport, and water infrastructure assets or a reduction in the efficiency of infrastructure services and operations. The critical infrastructure in Sekondi-Takoradi, such as power plants, gas pipelines, and roads, are located along the coastline rendering the infrastructure highly exposed to climate risks.

Human activities such as illegal mining, deforestation, and failure to comply with the existing regulations and policies further exacerbate the vulnerability of the factors contributing to economic and social disruptions due to critical infrastructural failure are shown in Figure 39.

Figure 39 I Critical infrastructure Impact Chain Diagram



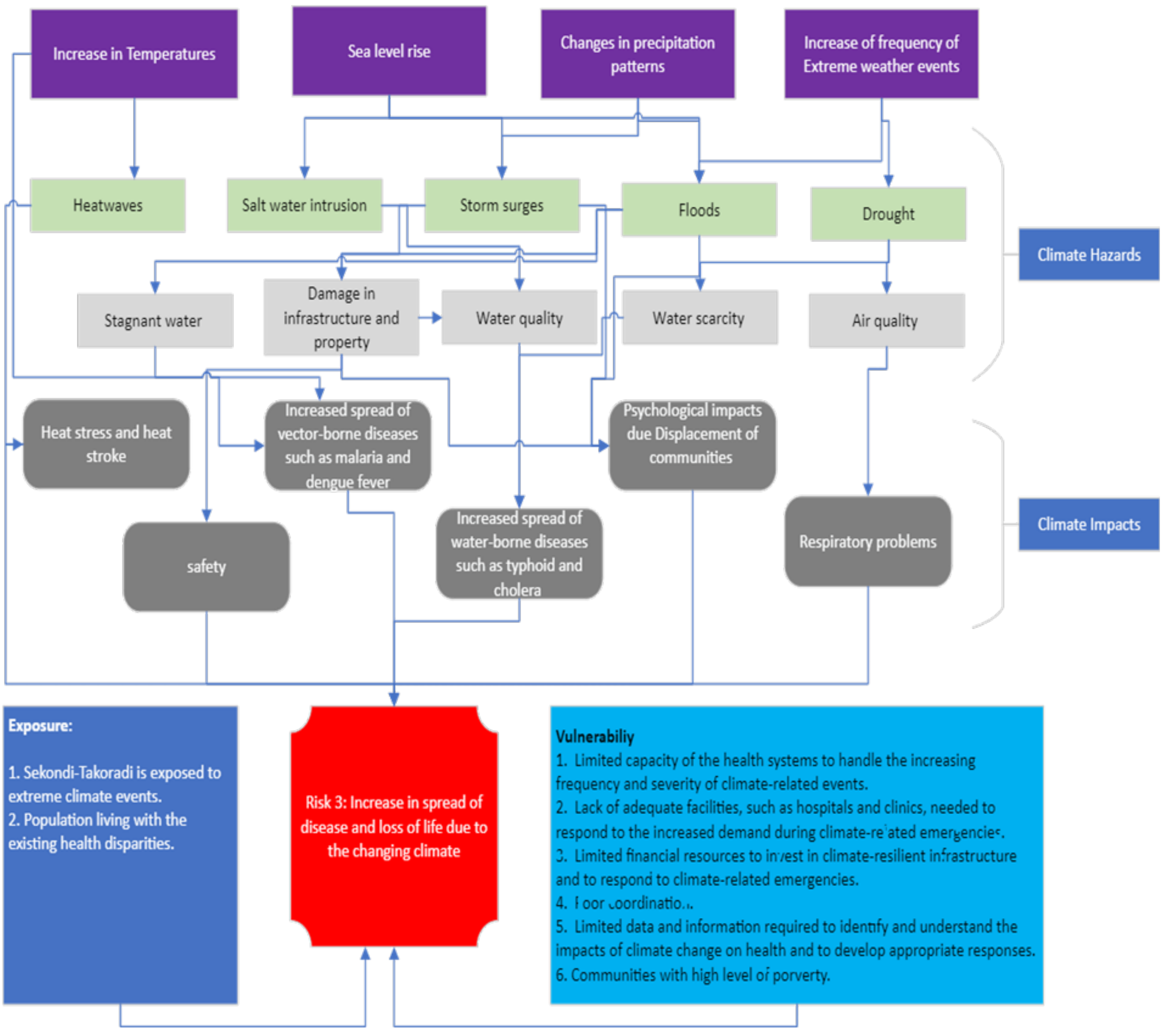
8.3.3 Risk 3: Community Health: Spread of disease and loss of life

The factors contributing to an increased risk to human health are shown in Figure 40. Climate change impacts are far-reaching and detrimental to human health, affecting mental and physical health. Sekondi-Takoradi is particularly vulnerable to climate hazards such as heatwaves, floods, saltwater intrusion and drought, affecting the community health through some of the following climate impacts: increased heat stress and stroke, increase in vector- and water-borne 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. For example, anopheles mosquitos are becoming a year-round threat in part because improper solid waste management is promoting their breeding; and malaria is changing from a seasonal to year-round threat (Mattah P. A., Futagbi, Amekudzi, & Mattah, 2020). The primary source of irrigation for vegetable crops in STMA is the central drainage systems, which carry untreated human-generated wastewater from homes, complemented by effluent from manufacturing/processing industries (Habib and Mensah, 2020). This is another source of disease (Habib & Mensah, 2020).

The conditions are exacerbated by underlying vulnerabilities such as 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 vulnerable to these climate-related risks.

Figure 40 I Health system Impact Chain Diagram



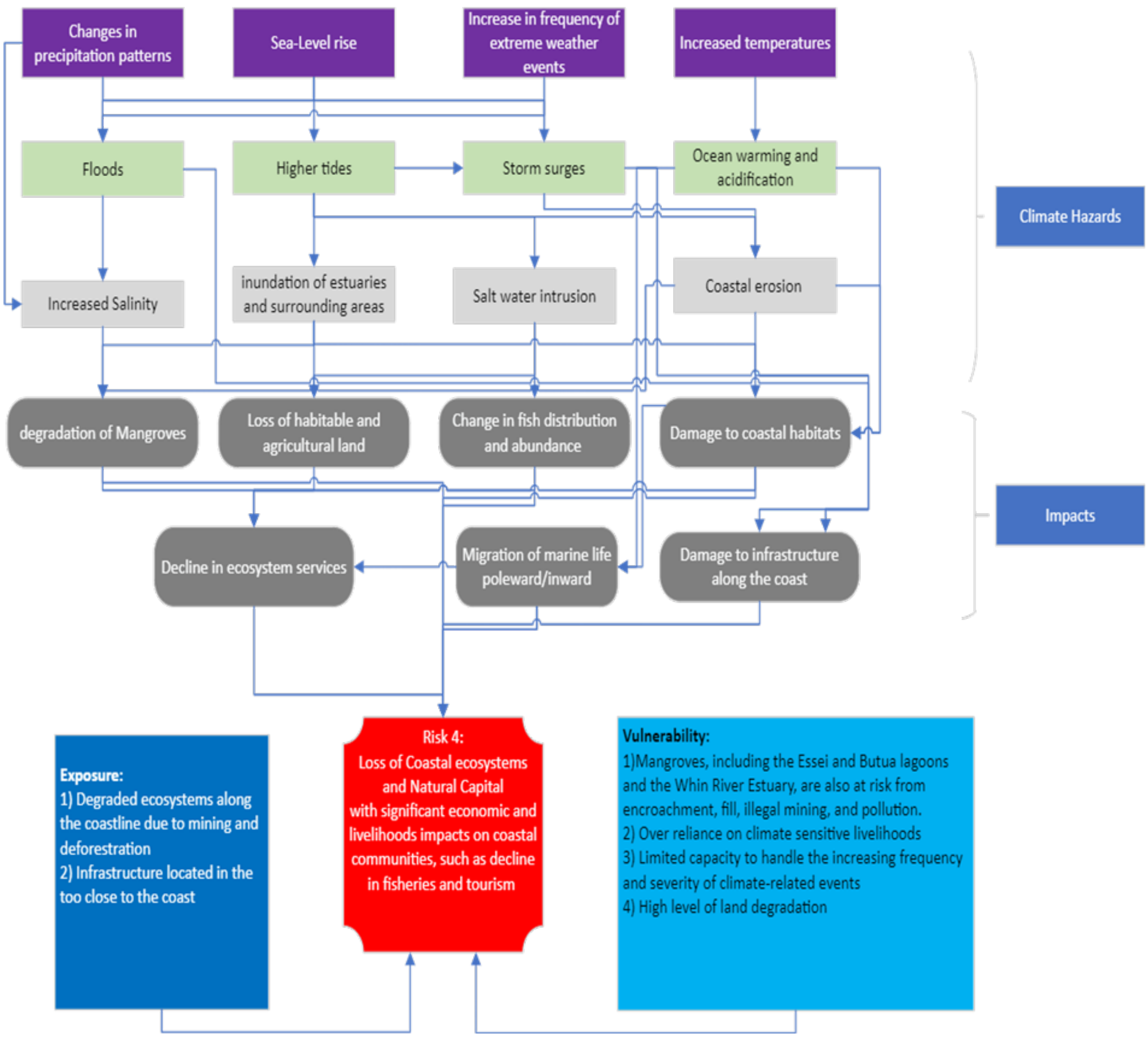
8.3.4 Risk 4: Decline in Coastal Ecosystems

Human activities such as encroachment, fill, illegal mining, and pollution, which threaten the coastal ecosystem, have destroyed habitats such as mangrove forests, wetlands, and coral reefs. One study (Dadzie-Paintsil & Mensah, 2022), based on extensive interviews and observations, found that people have mixed views of coastal ecosystems: while they recognize their value, for example as fish breeding grounds, they also perceive them as a threat because of mosquito breeding. They are often used as dumping grounds for solid waste because many residents perceive them as useless wasteland or as areas to be encroached for settlement. Climate change is adding pressure on the already fragile ecosystem by increasing the rate of loss of coastal ecosystems.

Climate change impacts such as sea-level rise, coastal flooding, erosion, inundation of coastal ecosystems, increasing temperature and acidification are changing the coastal ecosystems by degrading mangroves, changing the fish distribution, reducing fish supply and damage to coastal habitats. Climate change impacts will, in turn, reduce ecosystem services and natural capital and have significant consequences on the economy and the livelihoods of coastal communities.

The communities that are highly dependent on climate-sensitive livelihoods and lack resources to improve their adaptive capacity such as small scale fishers will suffer the most severe consequences.

Figure 41 I Coastal Ecosystem impact chain



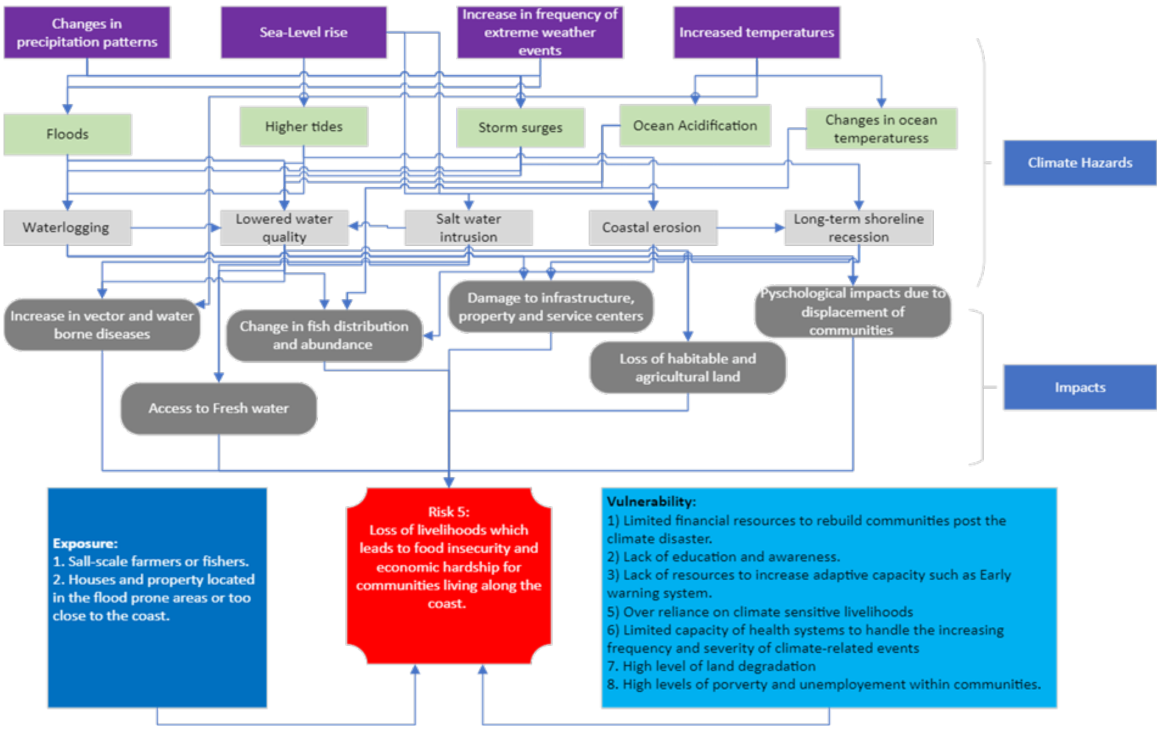
8.3.5 Risk 5: Loss of Livelihoods

The factors contributing to an increased risk to livelihoods are shown in Figure 42. In Sekondi-Takoradi, many local communities rely on fishing for their livelihoods. However, other livelihoods such as trade and commerce, manufacturing, and services are also important. Livelihoods in Sekondi-Takoradi are affected by the climate hazards; Sea level rise, flooding, heavy rainfall, drought, increased temperature, and evaporation which increases the exposure (to climate impacts) of small-scale fishers, women and girls, the unemployed, poverty-stricken communities, and those living within the coastline.

Flooding is a serious annual event and is being exacerbated by unplanned urban expansions at the expense of forest and agricultural land. Urban expansion is having serious hydrological consequences in terms of flooding, groundwater subsidence, and saltwater intrusion (AlQattan, Acheampong, Jaward, Vijayakumar, & Enomah, 2020). Residential areas along the five major rivers are frequently flooded. Urbanization, building in waterways and low-lying areas, reduction in flow capacity of channels due to siltation, overgrown vegetation, accumulation of solid waste, and general lack of maintenance of the drainage infrastructure are reported to have exposed the metropolis to high incidence of flooding (Owusu, Yankson, Asiedu, & Tutu-Benefor, 2019). Common coping strategies adopted by residents in flood-prone communities include temporary vacation of homes (the most common response), transfer of relevant properties to neighbours and building of flood steps (Samuel Yaw Danso, 2017).

In the region, climate change impacts will also be experienced through coastal erosion, saltwater intrusion, high rates of land degradation, which affects livelihoods by reducing fish stock and altering distribution of some fish species, increasing water- and vector-borne disease, damaging infrastructure, and disrupting services along the coast, loss of arable and habitable land. These impacts will increase the vulnerability of the communities dependent on climate-sensitive livelihoods and lack of resources to improve their adaptive capacity. These impacts will disproportionately affect women and girls who are often responsible for domestic and subsistence activities, including water collection, food production, and subsistence fisheries and agriculture. The reduction in water availability and increased water- and vector-borne disease 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 42 I Loss of Livelihoods Impact Chain Diagram



8.3.6 Risk 6: Water Security

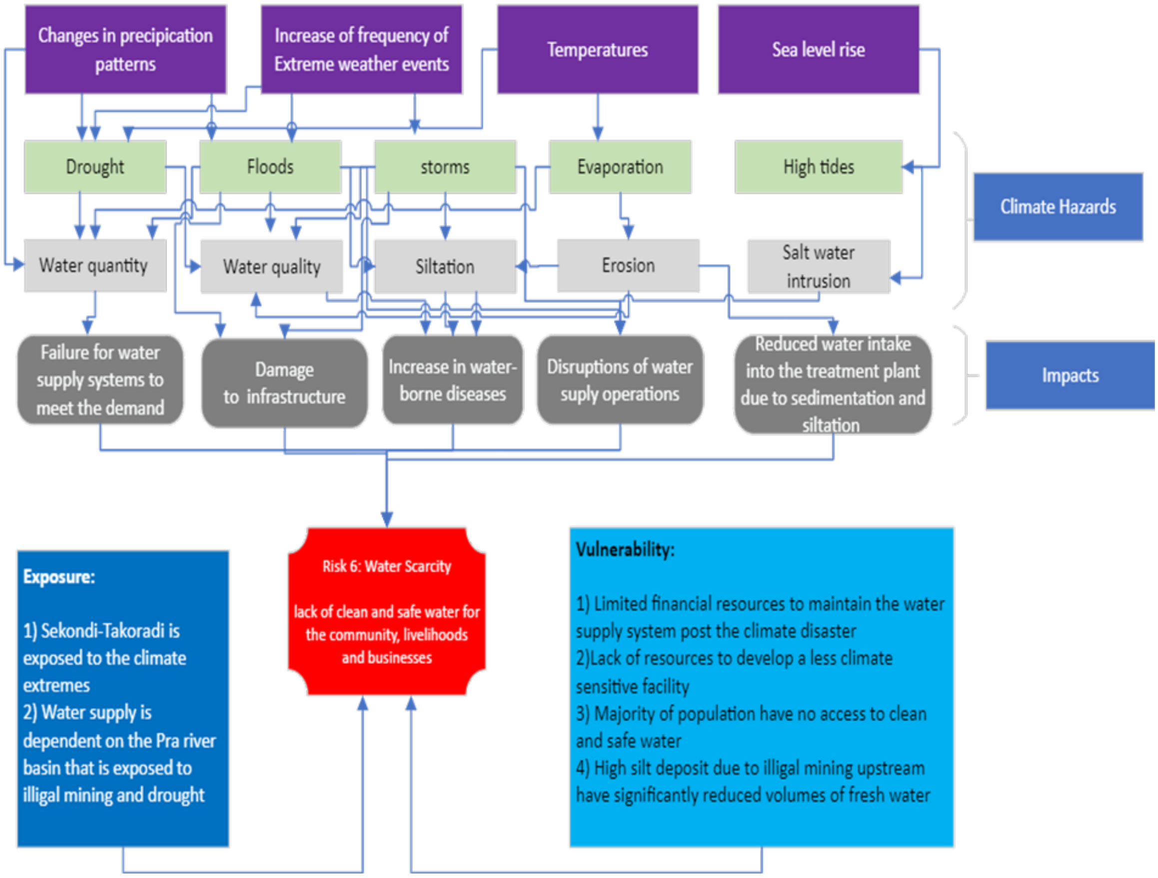
Climate change is expected to exacerbate water scarcity. Droughts, rising temperatures and changing precipitation patterns, siltation and sedimentation can lead to altered river flows, which can decrease the availability of fresh water for human and ecosystem needs. In January 2022, the Ghana Water Company Limited (GWCL) had to implement a water rationing strategy Sekondi-Takoradi due to the low level of water at the treatment plant because of the delayed rainfall. Sekondi-Takoradi has a high risk of significantly higher temperatures under all emission scenarios, even at lower GHG concentration scenarios. Precipitation projections are statistically insignificant under lower emission scenarios.

Future 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 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 and water supply infrastructure and contaminating water supplies. Increased flooding also leads to increased costs for the treatment of water for drinking. 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 (Antwi-Agyei, Abu, & Okyere-Nyako, 2021)..

The reduction in water availability 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 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.

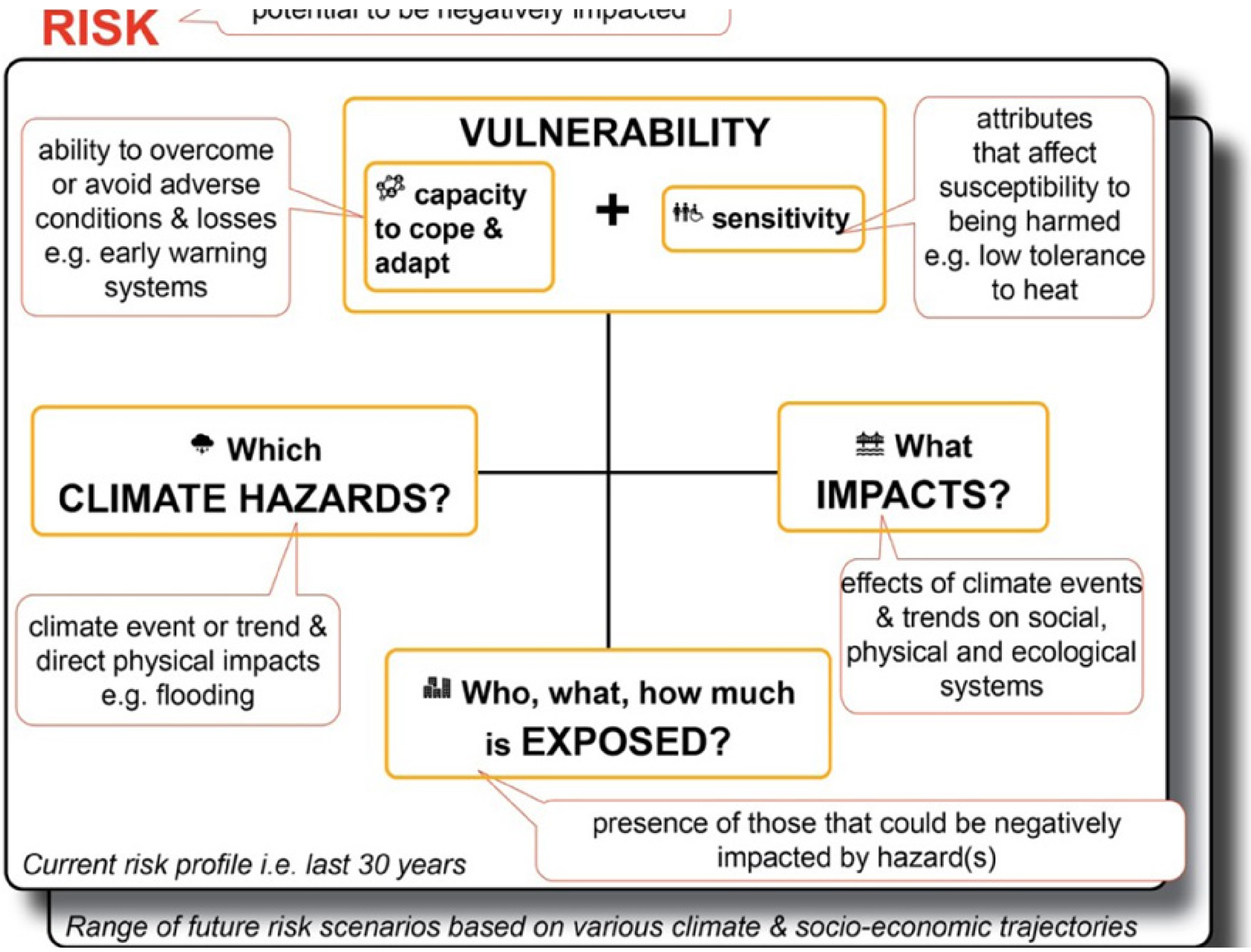
Figure 43 I Water Security Impact Chain Diagram



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 from (AR5) (2014), where risk is a core concept, and vulnerability 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 potentially impacted or harmed, that could be adversely affected (Department of Environment, Forestry and Fisheries, 2020).

Figure 44 I The component of climate vulnerability and climate risk, adapted from IPCC AR5



Source: National Climate Risk and Vulnerability (CRV) Assessment Framework summary document, 2020

In this study, the risk is defined as a function of hazard, exposure and vulnerability and assessed as probable harm that can be caused to a biophysical or socio-economic system by an anticipated threat.

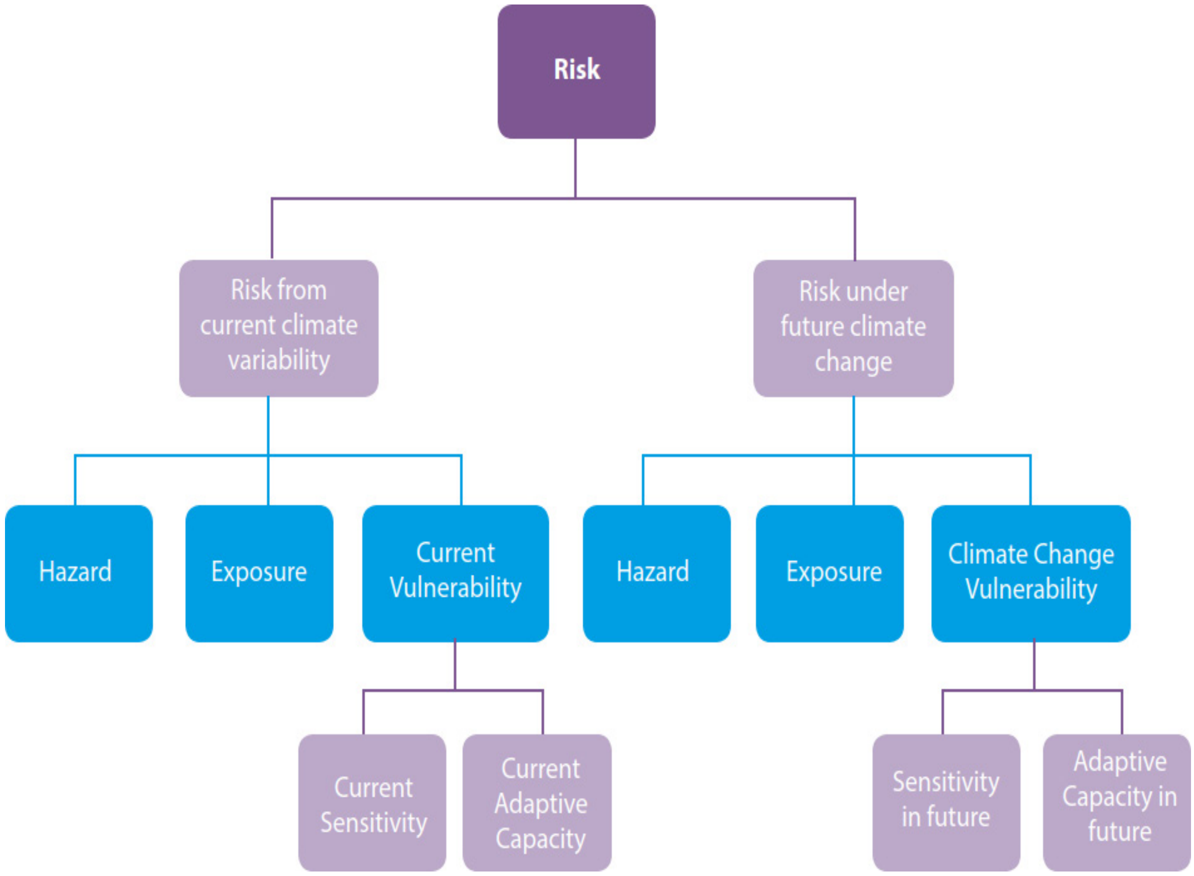
The vulnerability component of risk focuses on the sensitivity and adaptive capacity of those or that exposed to certain climate hazards. The approach to risk assessment involved collating and analysing information from the stakeholders' consultations and literature, considering the three elements that result in risk: exposure (E), hazard (H) and vulnerability (V).

$$\text{Risk} = f(H,E,V)$$

The assessment involved:

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

Figure 45 I 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 a 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 such as in Table 14.

Table 14 I Climate hazard thresholds 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%

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 drought hazard, water resource availability and crop suitability for primary crops under different climate change scenarios. The criteria to define the magnitude of the hazard is included in Appendix C.

8.4.2 Exposure

The exposure to hazards such as increasing flood risk can be supported by hazard mapping, as mentioned above with regards to flood hazard mapping study for Ghana: 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 analysis showed that the people or assets exposure to flood risk does not necessarily significantly increase with different climate scenarios, but the frequency and magnitude of these might change which is driven primarily by changes in extreme rainfall events.

Exposure was analysed by evaluating the history of past and recent weather events in the STMA. 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 C.

8.4.3 Vulnerability

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

The purpose of this stage is to assess vulnerability conditions based on exposure, and the sensitivities and adaptive capacity. The vulnerability can be defined as a composite of two aspects of sensitivity and capacity. Sensitivity includes the physical environment and socio-economic or cultural dynamics.

As the first step, the participatory approach was adopted, to profile sectors within the MMDA. The profiles will exhibit the general status quo including the biophysical and socio-economic 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, is dependent on socio-economic factors. It has been established that climate change will exacerbate the existing socio-economic problems within the province.

The vulnerability of communities with in the STMA was analysed using the feedback from the stakeholder engagement and review of published sources. Subsequently, the 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 directly or indirectly linked to climate risks will be considered in assessing the vulnerability.

The vulnerability of a natural ecosystem or socioeconomic system was assessed as a function of its sensitivity to such a hazard and its adaptive capacity to overcome such sensitivity. In this assessment, high vulnerability is expressed as a situation where the system that is exposed to climate risks has high sensitivity and low the adaptive capacity. Vulnerability is expressed as:

VULNERABILITY = SENSITIVITY - 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 assets are included in Appendix C.

8.4.4 Evaluating Risk

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

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

In Appendix C is 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, socio-economic sectors and local livelihoods.

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 in Section 8.4 and conceptual framework presented in Figure 45. Understanding the risks at a local level requires an integrative approach that looks at both the physical climate hazards and social dimensions of vulnerability. The stakeholders were engaged to identify the critical assets and systems exposed to climate hazards and shared their perspectives and experiences of the climate events that had adversely affected their systems of interests and challenges that they had to face as a result of such events.

The engagement revealed that the population seems to be more interested and aware of climate change issues and 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 of recruiting volunteers because they don't receive payment, but the Department is addressing this with a new initiative.
- There is an effective health communication system.
- Forestry personnel collaborate well with the fringe communities who have communication protocols.
- Fringe community members have been trained in basic firefighting skills
- There is an active movement to use digital technologies to address hazards. Apps have been developed in the following fields:

- Forestry: to report fires and also illegal cutting.
- Fisheries: to report illegal fishing and catching of mammals (this is a project whose data will feed directly back into government for policy making purposes)

- The data collected for marine mammals is included in CETA-BASE
- People with disabilities are always included into engagements and have a good working relationship with government officials.

During the workshop there was a suggestion that an improvement can be made on the reporting of Ghana Meteorological Agency (GMet) weather information to communities. This is only reported on television or can be accessed on smart phones. There are challenges met with disseminating the information further, but this would be good information to have disseminated further as it could assist with early warning to communities of flooding, heat waves, etc.

The discussions led to the results presented in the Table 15 and Table 16 below in terms of the current and potential future climate related risks. In addition, the outputs of climate models were used to inform the assessment of the future climate related risks, where the different scenarios were considered.

8.5.2 Adaptive Capacity and Residual Climate Change Risks

Sekondi-Takoradi is located in a region vulnerable to climate and weather extremes, including high sea level rise, floods and storms. Climate change projections for Sekondi- Takoradi suggests increasing average temperature from between 3 to 4.5 °C under RCP 8.5 with RCP 4.5 suggesting a mid-point of about 2.0 °C. The maximum temperatures and heatwave events are also expected to increase, thus increasing sea water temperatures and rate of evaporation. 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. Based on 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 Sekondi-Takoradi (see Table 18). The identified critical risks under the current and future conditions are rated high to extreme, but with the suggested risk mitigations measures, the level of risk is expected can be reduced.

The residual climate change risk assessment results are presented in Table 17, ranking current, future, and residual risks from Low to the Extreme. According to the results of the residual risk assessment, climate risk mitigation measures (adaptation) can reduce some elements of risk, such as sensitivity, and enhance adaptive capacity. Reducing risk requires modifying current policies and programs and implementing policies that explicitly consider climate variability and climate change.

The proposed adaptation measures listed below are initial recommendations and focus more on reducing the sensitivity and enhancing the capacity hence building a more resilient system. Further consideration should be given to the identification of priority adaptation responses that can then be included in the development of a specific climate change response plan for Sekondi-Takoradi.

Table 15 I Assessment of current climate change risks

Asset / System	Hazard Description	H	E	HxE	AC	S	V	Comment- Impacts	CCR
Fishery Industries	The observed changes in temperature, sea level rise, extreme weather events, such as hurricanes, typhoons, and storms have led to the loss of coastal habitats such as wetlands and estuaries, reduce fish populations, and impact the economic viability of fishery industries.	High	High	High	Moderate	High	High	1. The changes in temperature and PH level of the sea cause significant changes in the composition of fish populations, affecting the livelihoods of communities and the availability of seafood. 2. The sea level rise may lead to the loss of coastal habitats such as wetlands and estuaries, reduce fish populations, and impact the economic viability of fishery industries. The wetlands and estuaries can be inundated, losing essential spawning and nursery areas for fish and other marine species. 3. Extreme weather events, such as hurricanes, typhoons, and storms, can damage fishing infrastructure, affect coastal communities (safety) and disrupt fishing activities for extended periods. 4. Fishing patterns have changed, for instance, the Shama fishing industry has collapsed. Fishermen used to fish in wetlands or other areas which are now dry.	High
Water Supply Systems and Infrastructure	Extreme weather events, such as storms, floods, droughts and changing precipitation patterns are affecting the availability and the quality of the water for communities and businesses.	High	High	High	Low	High	High	1. Extreme weather events, such as storms and floods can cause damage to water supply infrastructure and disrupt operations. 2. Droughts and changing precipitation patterns can affect the availability and the quality of the water for communities and businesses using both local sources and regional water sources. 3. Prolonged dry periods can lead to lower river and stream flows. 4. Flooding causes erosion, and increased sediment loads in rivers leading to the reduced flow of water and quality of water resources.	High

Asset / System	Hazard Description	H	E	HxE	AC	S	V	Comment- Impacts	CCR
Critical infrastructure	The observed sea level rise is causing coastal flooding, storm surges, high tides and coastal erosion. all these hazards damage infrastructure and disrupt operations and business activities. The Extreme weather events such as erratic rainfall and flooding are now becoming common. Communities reported that some roads that used to only occasionally (seasonally) be flooded and are now flooded often at high tide or during heavy precipitation.	High	High	High	Moderate	High	High	1. Sea level rise will cause coastal flooding, storm surges, high tides and coastal erosion and all these hazards damage infrastructure and disrupt operations and business activities. The Ghana gas pipeline is exposed in some areas due to coastal erosion. 2. Many reports of beaches, houses and communities that have been washed away over the years, due to sea level rise. 3. The increased sea-level heights impede drainage system as there is more backwash. 4. Increased coastal flooding damages critical infrastructure such as roads, bridges, gas pipelines and buildings, disrupting transportation and business activities. 5. floods can also cause inundation of beach areas and ecosystems, landslides, and erosion, rendering roads impassable and difficult to access. 6. Storm surges can damage or destroy roads, bridges, and other infrastructure along the coast, causing disruptions to business activities, transportation and access to essential services. 7. High temperatures can cause roads to expand and contract, leading to cracking, potholes, and other types of damage. 8. In some cases, people were forced to leave their homes due to flash floods, leading to homelessness and other social disruptions.	High

Asset / System	Hazard Description	H	E	HxE	AC	S	V	Comment- Impacts	CCR
Agriculture	Rising temperatures, extreme weather events, changing precipitation patterns, water logging, drought, extreme heat, and storms are adversely affecting agriculture production and increase the risk of infestation of pest and diseases leading to crop failure and reduced livestock production.	High	High	High	Moderate	High	High	1. 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, water logging, drought, extreme heat, and storms. Potential change in crop suitability. 2. Increasing temperatures and precipitation are likely to increase the risk of infestation of pest and diseases leading to crop failure and reduced livestock production.	High
Health systems	Floods, stagnant waters, increased temperatures, and other extreme climate events affect negatively human health and health systems	High	High	High	Moderate	High	High	More cases of Malaria are being reported during the rainy season.	High
Coastal Ecosystems	The observed changes in temperature, sea level rise, extreme weather events, such as hurricanes, typhoons, and storms have led to the loss of coastal habitats such as wetlands and estuaries, reduce fish populations, and impact the coastal ecosystems	High	High	High	Low	High	High	Impacts of climate change in coastal ecosystems, include losses of species habitat and diversity, and degradation of ecosystem functions. During the stakeholder's consultation Fishermen attested to the increased runoff from rivers into the ocean. The inlets affect the current and release a lot more sediment into the ocean. This has impacted where the fishermen go to fish.	High

H: Hazard Score **E: Exposure** **AC: Adaptive Capacity** **S: SensitivityVulnerability** **HxE: Hazard x Exposure** **CCR: Climate Change Risk**

Table 16 I Assessment of future climate change risks

Asset / System	Hazard Description	H	E	HxE	AC	S	V	Comment- Impacts	CCR
Fishery Industries	The maximum catch potential of fisheries is projected to decline by 20.5–24.1% by the end of the 21st century relative to 1986–2005 under RCP8.5 (medium confidence) (IPCC,2014). The decline is attributed to increasing ocean temperature, enhanced stratification and acidification. Sekondi-Takoradi is located in the Tropics, and according to IPCC marine animal biomass and production are projected to decrease more than the global average under all emissions scenarios in the 21st century (high confidence) (IPCC, 2014). By 2100, sea levels near Sekondi-Takoradi are expected to rise by approximately 0.4 meters relative to historical sea levels under RCP 4.5, which will threaten coastal habitats and exacerbate coastal erosion (World Bank, 2021).	Very high	Very high	Extreme	Moderate	High	High	Communities along the coast depend on fisheries for food and livelihoods. A decrease in the catch potential of fisheries, can lead to a decline in economic benefits, potential job losses, and food security.	Extreme
Water Supply Systems and Infrastructure	Precipitation is highly variable however the projections suggest wetter conditions over Sekondi-Takoradi, 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 event.	Very high	High	Extreme	Moderate	High	High	1. 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. 2. 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. 3. Water scarcity can have economic impacts, as it can lead to a decline in agricultural productivity.	Extreme
Critical infrastructure	IPCC has predicted with high confidence that the Sea level will continue to rise at an increasing rate. Global mean sea level rise will cause the frequency of extreme sea level events such as high tides, storm surges, strong winds, and changes in ocean currents at most locations to increase (IPCC,2014). By 2100, sea levels near Sekondi-Takoradi are expected to rise by approximately 0.4 meters relative to historical sea levels under RCP 4.5, which will exacerbate coastal erosion (World Bank, 2021).	Very high	High	Extreme	Moderate	High	High	The extreme sea level events will likely cause disruptions and damage to transportation systems, energy systems, water supply and sanitation, ports and shipping infrastructure, and communication infrastructure. The impacts are far-reaching and cascading effects on the functioning of society. Access to basic services will become difficult and the livelihoods and economy will be negatively impacted.	Extreme

Asset / System	Hazard Description	H	E	HxE	AC	S	V	Comment- Impacts	CCR
Agriculture	The projected sea level rise will likely exacerbate coastal erosion, inundation of estuaries and surrounding areas, and saltwater intrusion. Precipitation is highly variable however the projections suggest wetter conditions over Sekondi-Takoradi, and yet there is high confidence that temperatures are expected to increase under both CMIP5 and CMIP6 projections. Frequent flooding and waterlogging is highly possible in the future but the increase in temperature will likely increase the rate of evaporation and therefore affect water availability.	Very high	Very high	Extreme	Moderate	High	High	Saltwater intrusion into freshwater aquifers and agricultural lands can lead to reduced yields or even complete loss of crops. Climate change is also expected to increase the frequency and intensity of extreme weather events, such as hurricanes, typhoons, and flooding, that will cause extensive damage to crops, infrastructure, and the livelihoods of farmers	Extreme
Health systems	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. The projected wetter conditions (on average) and increase in temperatures are likely to increase risk of vector-borne and water-borne diseases. Increasing flood risks could damage critical infrastructure and limit access to hospitals and other health care facilities. Temperatures and the intensity and frequency of heat waves are expected to increase in future	Very high	Very high	Extreme	Moderate	High	High	Climate change impacts on health will include the increased risk of waterborne diseases, heat-related illnesses, malnutrition due to food insecurity, vector-borne diseases, and potential psychological issues due to displacement and migration because of sea-level rise and other climate-related events. Increase in mean annual temperature and in the intensity and frequency of heat waves could result in a greater number of people at risk of heat-related medical conditions.	Extreme
Coastal Ecosystems	Coastal ecosystems are projected to face increasing risk levels, from high to very high risk under RCP8.5, by 2100 due to exposure to ocean warming, sea level rise, acidification, and inundation of coastal ecosystems (IPCC.2014). Sekondi-Takoradi is located in the Tropics, and according to IPCC, the marine animal biomass and production are projected to decrease more than the global average under all emissions scenarios in the 21st century (high confidence).	Very high	Very high	Extreme	Moderate	High	High	Impacts of climate change in coastal ecosystems, include losses of species habitat and diversity, and degradation of ecosystem functions. The loss of coastal ecosystems will adversely impact the coastal communities by affecting income, livelihoods, and food security of marine resource-dependent communities.	Extreme

H: Hazard Score **E: Exposure** **AC: Adaptive Capacity** **S: SensitivityVulnerability** **HxE: Hazard x Exposure** **CCR: Climate Change Risk**

Table 17 | Assessment of Future Residual Risk after implementation of adaptation measures

Asset / System	Hazard Description	Residual Adaptive capacity	Sensitivity	Exposure	Vulnerability	Residual Risk
Fishery Industries	1. Build seawalls, breakwaters, and other physical structures can help protect fishery infrastructure from sea level rise, storm surges, and other extreme weather events. 2. Implement ecosystem-based or nature-based solutions, such as mangrove restoration and green infrastructure. 3. Reduce the use of fertilizers and pesticides, can help reduce the impacts of climate change on coastal ecosystems. 4. Strengthen the early warning systems and improving infrastructure can help reduce the impacts of extreme weather events and other disasters on coastal communities and ecosystems.	High	Moderate	High	Medium	High
Water Supply Systems and Infrastructure	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. Implement effective land use planning to reduce flooding in future 5. Improve the resilience and capacity of infrastructure to cope with extreme weather events.	Moderate	Moderate	Medium	Medium	Medium

Asset / System	Hazard Description	Residual Adaptive capacity	Sensitivity	Exposure	Vulnerability	Residual Risk
Critical infrastructure	1. To ensure the resilience of critical infrastructure over time, implement adaptive management practices that can help to monitor and respond to changing climate conditions, such as sea level rise and changing weather patterns. 2. Implement nature-based solutions and green infrastructure as protection measures for protection of the infrastructure 3. Retrofit infrastructure by elevating structures, strengthening foundations, and adding flood barriers to help protect the infrastructure against sea level rise, storm surge, and flooding. 4. Create redundant or backup systems, such as power generators and alternative routes for transportation, to maintain critical services during extreme weather events and other disasters. 5. Minimize the impacts on critical infrastructure and the communities by strengthening the early warning systems to provide in advance the notice of extreme weather events and other hazards. 6. Conduct risk assessments and develop adaptation plans for specific infrastructure to help identify vulnerable areas and prioritize adaptation measures to protect infrastructure. 7. Implement flood control measure to minimise the impacts of flooding on critical infrastructure	High	Moderate	High	Medium	High
Agriculture	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.	Moderate	Moderate	Medium	Medium	Medium

Asset / System	Hazard Description	Residual Adaptive capacity	Sensitivity	Exposure	Vulnerability	Residual Risk
Health systems	1. Improve water and sanitation systems to reduce the risk of waterborne diseases. 2. Implement heat emergency response plans to prevent heat-related illnesses. 3. Improve food security through sustainable agriculture and fisheries practices. 4. Strengthen vector control measures to reduce the incidence of vector-borne diseases 5. Implement wastewater treatment to reduce use of untreated wastewater to irrigate vegetables.	Moderate	Moderate	Medium	Medium	Medium
Coastal Ecosystems	1. Implement the integration of ecosystem-based or nature-based solutions, such as mangrove restoration and green infrastructure. 2. Build seawalls, breakwaters, and other physical structures where critical infrastructure is threatened, to help protecting coastal ecosystems from sea level rise, storm surges, and other extreme weather events. 3. Promote sustainable land use practices, including reducing deforestation, limiting development in vulnerable coastal areas. 4. Reducing the use of fertilizers and pesticides, can help reduce the impacts of climate change on coastal ecosystems. 5. Strengthen the early warning systems and improving infrastructure can help reduce the impacts of extreme weather events and other disasters on coastal communities and ecosystems. 6. Improve the law enforcement to stop disposal of solid waste in coastal wetlands and stop encroachment	Moderate	Moderate	High	Medium	High

H: Hazard Score **E: Exposure** **AC: Adaptive Capacity** **S: SensitivityVulnerability** **HxE: Hazard x Exposure** **CCR: Climate Change Risk**

Table 18 I Climate change risk assessment results matrix and short narrative explaining the risk

Asset / System	Hazard Description	Residual Adaptive capacity	Sensitivity	Exposure
Fishery Industries	The maximum catch potential of fisheries is projected to decline by 20.5–24.1% by the end of the 21st century relative to 1986–2005 under RCP8.5 (medium confidence). The decline is attributed to increasing ocean temperature, enhanced stratification and acidification. Sekondi-Takoradi is located in the Tropics, and according to IPCC marine animal biomass and production are projected to decrease more than the global average under all emissions scenarios in the 21st century (high confidence). By 2100, sea levels near Sekondi-Takoradi are expected to rise by approximately 0.4 meters relative to historical sea levels under RCP 4.5, which will threaten coastal habitats and exacerbate coastal erosion (World Bank, 2021).	High	Extreme	High
Water Supply Systems and Infrastructure	Precipitation is highly variable however the projections suggest wetter conditions over Sekondi-Takoradi, 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.	High	Extreme	Medium
Critical infrastructure	IPCC has predicted with high confidence that the Sea level will continue to rise at an increasing rate. Global mean sea level rise will cause the frequency of extreme sea level events such as high tides, storm surges, strong winds, and changes in ocean currents at most locations to increase (IPCC,2014). By 2100, sea levels near Sekondi-Takoradi are expected to rise by approximately 0.4 meters relative to historical sea levels under RCP 4.5, which will exacerbate the risk of coastal erosion and flooding (World Bank, 2021). In addition to these coastal threats, there is a possibility of river flooding in the future that could potentially damage infrastructure as a result of more intense precipitation events and changing rainfall patterns associated with climate change. Climate change impacts will bring economic and social disruptions due to critical infrastructural failure.	High	Extreme	High
Agriculture	The projected sea level rise will likely exacerbate coastal erosion, inundation of estuaries and surrounding areas, and saltwater intrusion. Precipitation is highly variable however the projections suggest wetter conditions over Sekondi-Takoradi, and yet there is high confidence that temperatures are expected to increase under both CMIP5 and CMIP6 projections. Frequent flooding and waterlogging is highly possible in the future but the increase in temperature will likely increase the rate of evaporation and therefore affect water availability. All these will	High	Extreme	Medium
Health systems	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. The projected wetter conditions (on average) and increase in temperatures are likely to increase risk of spread of vector-borne and water-borne diseases. Increasing flood risks could damage critical infrastructure and limit access to hospitals and other health care facilities. Increase in mean annual temperature and in the intensity and frequency of heat waves could result in a greater number of people at risk of heat-related medical conditions.	High	Extreme	Medium

Asset / System	Hazard Description	Residual Adaptive capacity	Sensitivity	Exposure
Coastal Ecosystems	Coastal ecosystems are projected to face increasing risk levels, from high to very high risk under RCP8.5, by 2100 due to exposure to ocean warming, sea level rise, acidification, and inundation of coastal ecosystems (IPCC.2014). Sekondi-Takoradi is located in the tropics, and according to IPCC, the marine animal biomass and production are projected to decrease more than the global average under all emissions scenarios in the 21st century (high confidence).	High	Extreme	High

9 Conclusion and Recommendations

9.1 Future Climate Change Scenarios for STMA

Future climate change projections show a risk of significantly higher temperatures for Sekondi- Takoradi Metropolitan Assembly even at lower GHG concentration scenarios, by mid-century, by 2 °C, and varying from 1.5 up to 4°C, by the end of the century, depending on the emission scenario. However, precipitation projections remain highly variable and uncertain. There is a roughly equal chance of small increases and decreases in annual average precipitation compared to the base years, typically around a 10% increase and decrease. The extremes suggest the possibility of change of up to 20% +/- in mean annual precipitation. 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 RCP 4.5 and RCP 8.5 scenarios for most of the models leading to potential increase in flooding.

9.2 Priority Climate Related Hazards and Risks

For STMA, seven first and second-order priority risk domains where identified that have a significant number of climate change hazards associated with them. These included the following:

- Water Resources
- Erosion and Sedimentation
- Coastal Flooding
- Ecosystems
- Energy Security (e.g., thermal)
- Transport Systems
- Fisheries

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 STMA on the 1st December 2022.

- The most prominent climate hazards for STMA are extreme heat, sea-level rise and river and urban flooding.
- The observed changes in temperature, sea level rise, and extreme weather events, such as hurricanes, typhoons, and storms, have led to the loss of coastal habitats, reduced fish populations and impacted the economic viability of fishery industries.

- Rising mean sea levels, potential increases in the frequency/intensity of storms, high wind speeds and extreme waves, could cause economic losses due to the direct damages to infrastructure and operational disruptions/delays to the port operational activities.
- Extreme weather events such as floods and droughts are affecting the availability and quality of water for communities and businesses.
- Critical infrastructure, such as roads and gas pipeline, has been exposed due to coastal erosion. The observed sea level rise is causing coastal flooding, storm surges, high tides and coastal erosion. All these hazards damage infrastructure and disrupt operations and business activities.
- Extreme weather events such as erratic rainfall and flooding are now becoming common. Communities reported that some roads only got flooded occasionally (seasonally) and are now flooded often at high tide or during heavy precipitation.
- Rising temperatures, extreme weather events, changing precipitation patterns, water logging, drought, extreme heat, and storms affect agricultural production and increase the risk of infestation of pest and diseases, leading to crop failure. Stakeholders confirmed that more pests and diseases are being recorded, even though the cause is unknown. For example, there was a snail infestation that was eating the roots of tress that had been planted as part of a forestry project to introduce a new species of tree into the region.
- Floods, stagnant waters, increased temperatures, and other extreme climate events negatively affect human health and health systems. Studies reveal a growing prevalence of malaria throughout the year, including during the dry season (Mattah P. A., Futagbi, Amekudzi, & Mattah, 2020). Factors such as wastewater from residential areas, agricultural irrigation, and industrial processing contribute to the creation of breeding grounds for mosquitoes even in less humid periods (Habib and Mensah, 2020).
- Changes in temperature, sea level rise, and extreme weather events, such as hurricanes, typhoons, and storms, have led to the loss of coastal habitats such as wetlands and estuaries (degradation at Essei and Butuah lagoons).

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 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 where:

- Impact on **fisheries** due increasing ocean temperature, enhanced stratification and acidification and sea-level rise which will threaten coastal habitats, exacerbate coastal erosion and lead to changes in the distribution and abundance of fish and other marine organisms.
- Damage to **critical infrastructure** sea-level rise which will cause the frequency of extreme sea level events such as high tides, storm surges, strong winds, and changes in ocean currents at most locations to increase thus will exacerbate the risk of coastal erosion and flooding. Climate impacts will bring economic and social disruptions due to critical infrastructural failure.

- Impact on **coastal ecosystems**. due to exposure to ocean warming, sea level rise, acidification, flooding, and inundation of coastal ecosystems, which may cause the marine animal biomass and production to decrease more than the global average under all emissions scenarios.

9.4 Potential Adaptation Options and Recommendations

The Ghanaian Government has been investing in integrating climate change objectives and priorities into sector-specific development plans in agriculture, transportation, and energy to mainstream climate change strategies and coordinate the strategic climate adaptation activities, in line with the country's socio-economic 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 the dissemination of information was found to be a crucial component for a successful climate change adaptation strategy for Sekondi-Takoradi. 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 STMA:

- General Adaptation Response Priority Projects for critical infrastructure

  - **Energy Sector:**
    - Coastal flood defence of thermal power plants in the Western region
    - Safeguarding vulnerable substations against floods and landslides
    - Capacity development and regulatory frameworks to support local renewable energy generation 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:**
    - Airport flood resilience through elevation of runways and other vulnerable components
    - Bridges and underpasses to ensure community access to services
    - Nature-based adaptation through creation of intertidal habitat at Takoradi
    - 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

– **Urban planning**:

- Review and update the 2005 Drainage Master Plan, due to the growth of the city since then, which should be complemented by more effective land use planning and regulation to preserve green spaces for flood waters. This would assess the current status of the masterplan's implementation, particularly with regard to the current urbanisation and drainage situation, and if the drains constructed remain suitable in size, to accommodate future rainfall events. There's a need to look at how all aspects of urban development, housing roads, and other sectors such as industry and government, have affected natural drainage systems and the extent to which this has exacerbated flooding.
- Ensuring coordination among the various government departments both vertically (between local, regional and national government entities) and horizontally (across jurisdictions, between other MMDAs) as well as linking to other programmes such as West Africa Coastal Areas Management Program (WACA) will be essential to ensure a more integrated approach to flood risk management and urban development in general. Consideration should be given to establishing governance arrangements that allow for watershed level management of land-use and other activities to improve the flood resilience and water resource management of cities.
- Develop, broadcast, and enforce zoning guidelines or other local regulations, to ensure encroachment on flood prone areas is avoided.

– **Cross-sectoral:**

- Sponge City measures to provide ecosystem-based urban adaptation to climate change
- Centralised climate-risk data management system
- Risk-resilient land 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
- Ecosystem based adaptation to address coastal erosion risks

Underlying many of these proposed interventions is the need to support the transition of Sekondi-Takoradi to becoming a more climate proof MMDA as this will help in addressing many of the existing climate related risks and help to improve liveability and productivity for Sekondi-Takoradi. Key to supporting the transition to a more climate proof MMDA or developing a strategy and identifying champions as well as putting in place the necessary information and tools to help with integrated urban planning is the implementation of Nature-based Solutions (NbS) across landscapes to build resilience to climate change. An example of some typical NbS and their benefits are shown in Figure 46.

Figure 46 I Nature-based solutions across landscapes to build resilience

Source: (Global Commission on Adaptation, 2019)

Nature-based solutions (NbS) involve working with nature to address societal challenges, providing benefits for both human well-being and biodiversity. Actions of NbS include protecting, sustainably managing and restoring natural and semi-natural (or modified) ecosystems, the sustainable management of aquatic systems and working lands such as croplands or timberlands; or the creation of novel ecosystems in and around cities. They are actions that are underpinned by biodiversity and are designed and implemented with the full engagement and consent of local communities and Indigenous Peoples. There is evidence showing that NbS have the capacity to reduce greenhouse gas emissions, (i.e., provide climate change mitigation benefits) as well as reduce the impact of climate-related shocks and stresses such as flooding and drought (i.e. climate change adaptation benefits). For different landscapes there are different NbS that can be implemented to adapt to climate change hazards.

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 47. These criteria should be considered when identifying priority actions for adapting to climate change in the STMA.

Figure 47 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 curent 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 chnage information can be disseminated
4. Formulate an adaptation strategy: What policies enhance adaptive capcity and encourage autonomous adaptation?	• Designing policies that identify trade-offs, synergies and conflicts between key sectors • Raising awareness, idenitfying and prioritising adaptation options and removing barriers are the principle elements of capacity developement
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 adaptatio • 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)

References

1. Acheampong, T., Menyeh, B. O., & Agbevivi, D. (2021, June 9). *Ghana's electricity supply mix has improved, but reliability and cost is still a challenge*. Retrieved from The Conversation: https://theconversation.com/ghanas-electricity-supply-mix-has-improved-but-reliability-and-cost-is-still-a-challenge-161762

2. Ackah, I. (2021). The Latest Power Supply Challenges in Ghana. Energy for Growth Hub. Retrieved from https://www.energyforgrowth.org/wp-content/uploads/2021/08/The-Latest-Power-Supply-Challenges-In-Ghana.pdf

3. Adapting to Climate Change in Time Project partners. (2020). *Planning for adaptation to climate change. Guidelines for municipalities.* Climate-ADAPT; Life Project No LIFE08 ENV/IT/000436. Retrieved from https://base-adaptation.eu/sites/default/files/306-guidelinesversionefinale20.pdf

4. Addo, I. Y., & Danso, S. Y. (2017). Sociocultural factors and perceptions associated with voluntary and permanent relocation of flood victims: A case study of Sekondi-Takoradi Metropolis in Ghana. *Jàmbá : Journal of Disaster Risk Studies, 9*. doi:https://doi.org/10.4102/jamba.v9i1.303

5. Addo, K. A. (2021). Ghana's coastline, swallowed by the sea. *The UNESCO Courier*(e-ISSN 2220-2293), pp. 10-11. Retrieved from https://en.unesco.org/courier/2021-1/ghanas-coastline-swallowed-sea

6. Adom, D., Appiah, S., & Yarney, L. (2019). A return to the Ghanaian cultural values of closed fishing season in Ghana's artisanal marine fishing: an essential means of restoring small pelagic fish stocks. *Transylvanian Review of Systematical and Ecological Research, 21*(3), 95-110. doi:10.2478/trser-2019-0020

7. Adshead, D., Thacker, S., Fuldauer, L., Gall, S., Chow, N., Pant, R., . . . Agbesi, L. (2022). *Ghana: Roadmap for resilient infrastructure in a changing climate.* Accra, Ghana: Ministry of Environment, Science, Technology & Innovation. Retrieved from https://gca.org/wp-content/uploads/2022/03/Ghana_Roadmap-for-Resilient-Infrastructure-in-a-Changing-Climate.pdf

8. Adusei, L. A. (2012). What are the sources of households' energy in Sekondi-Takoradi? *In document Energy poverty: exploring households energy constraints and coping strategies (Page 47-51)*. Uppsala, Sweden. Retrieved from https://1library.net/article/sources-households-energy-sekondi-takoradi.q7egoxnz

9. AlQattan, N., Acheampong, M., Jaward, F. M., Vijayakumar, N., & Enomah, L. E. (2020). Evaluation of the potential hydrological impacts of land use/cover change dynamics in Ghana's oil city.

10. *Environment, Development and Sustainability, 22*, 7313-7330. Retrieved from https://doi.org/10.1007/s10668-019-00507-0

11. Alves, B., Angnuureng, D. B., Morand, P., & Almar, R. (2020). A review on coastal erosion and flooding risks and best management practices in West Africa: what has been done and should be done. *Journal of Coastal Conservation, 24*(38). Retrieved from https://doi.org/10.1007/s11852-020-00755-7

12. Anthoff, D., & Tol, R. (2013). The Uncertainty about the Social Cost of Carbon: A Decomposition Analysis Using FUND. *Climatic Change, 117*, 515–530. doi:https://doi.org/10.1007/s10584-013-0706-7

13. Antwi-Agyei, P., Abu, M., & Okyere-Nyako, A. A. (2021). *Climate Change Gender Action Plan .* Accra: UNDP.

14. ARUP; Global Center on Adaptation. (2023). *Nature Base Solutions for Resilience - Infrastructure Pathways*. Retrieved from Infrastructure Pathways: https://infrastructure-pathways.org/use-case/nbs/

15. Ayilu, R. K., Fabinyi, M., Barclay, K., & Bawa, M. A. (2023). Blue economy: industrialisation and coastal fishing livelihoods in Ghana. *Reviews in Fish Biology and Fisheries*, 1-18. doi:doi: 10.1007/s11160-022-09749-0

16. Beguería, S., Latorre, B., Reig, F., & Vicente-Serrano, S. M. (2022). *SPEI Global Drought Monitor.*

17. Retrieved from SPEI, The Standardised Precipitation-Evapotranspiration Index: https://spei.csic.es/map/maps.html

18. Berger, R., Ensor, J., Wilson, K., Phukan, I., & Dasgupta, S. (2014). Adaptive capacity. *Community-Based Adaptation to Climate Change: Scaling it up*, pp. pp. 22–35. doi:https://doi.org/10.4324/9780203105061

19. Boateng, I. (2012). An application of GIS and coastal geomorphology for large scale assessment of coastal erosion and management: a case study of Ghana. *Journal of Coast Conservation, 16*, 383–397. doi:10.1007/s11852-012-0209-0

20. Bonsu, H. D. (2015). The Major Death Causing Diseases in Ghana (A Case Study of Sekondi Takoradi Metropolis). *International Journal of Scientific and Innovative Mathematical Research, 3*, 36-49.

21. Britannica . (2023). *Acrisol | FAO soil group | Britannica*. Retrieved from Encyclopedia Britannica | Britannica : https://www.britannica.com/science/Acrisol

22. Britannica. (2023). *Lixisol | FAO soil group | Britannica*. Retrieved from Encyclopedia Britannica | Britannica: https://www.britannica.com/science/Lixisol

23. Cardona, O., Aalst, M. v., Birkmann, J., Fordham, M., McGregor, G., Perez, R., . . . Sinh, B. (2012). Determinants of risk: exposure and vulnerability. *In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation(A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC))*, 65-108. (C. Field, V. Barros, T. Stocker, D. D. D. Qin, K. Ebi, M. Mastrandrea, . . . P. Midgley, Eds.) Cambridge, UK, and New York, NY, USA: Cambridge University Press. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap2_FINAL-1.pdf

24. Cervigni, R., Losos, A. M., Neumann, J. L., & Chinowsky, P. (2016). *Enhancing the climate resilience of Africa's Infrastructure: the roads and bridges sector.* Washington, D.C: The World Bank Group. Retrieved from https://www.worldbank.org/en/topic/transport/publication/enhancing-the-climate-resilience-of-africas-infrastructure-the-roads-and-bridges-sector

25. CHF International. (2010). *Sekondi-Takoradi Poverty Map: A guide to Urban Poverty Reduction in Sekondi-Takoradi.* Accra: STMA. Retrieved from https://www.alnap.org/system/files/content/resource/files/main/2011-sekondi-takoradi-poverty-map.pdf

26. Coastal Resource Center-Ghana/Friends of the Nation. (2010). *Rapid Biodiversity Assessment on the Essei and Butuah Lagoons and Whin River Estuary in the Sekondi-Takoradi Metropolis of the Western Region of Ghana.* Cape Coast: Coastal Resource Center-Ghana in Partnership with Friends of the Nation on the Hɛn Mpoano Initiative in Ghana. Retrieved from https://www.crc.uri.edu/download/GH2009STMA001_508.pdf

27. Coastal Resources Center. (2013). Coastal Hazards and Flooding Risk in Ghana's Western Region. Issue Brief 7 in series "Hɛn Mpoano: Our Coast, Our Future". *USAID Integrated Coastal and Fisheries Governance Program for the Western Region of Ghana*, 15pp. Narragansett, Rhode Island, USA: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. Retrieved from https://www.crc.uri.edu/download/GH2009COM009ib7_shore_508.pdf

28. Coastal Resources Center. (2013). Hɛn Mpoano Policy Brief No. 5, February 2013. Fresh Water Supply and Distribution: a Developing Crisis in the Western Region. *USAID Integrated Coastal and Fisheries Governance Program for the Western Region of Ghana*, 4 pp. Narragansett, Rhode Island, USA: Coastal Resources Center, University of Rhode Island. Retrieved from https://pdf.usaid.gov/pdf_docs/PA00JDSJ.pdf

29. CRIDF. (2015, November 6). *Final Resiliency Screening and Climate Change Risk Assessment Guidelines.* Climate Resilient Infrastructure Development Facility (CRIDF). Retrieved July 2021, from https://cridf.net/RC/wp-content/uploads/2018/04/Extlib22.pdf

30. Dadson, I. Y., Owusu, A. B., & Adams, O. (2016). Analysis of Shoreline Change along Cape Coast-Sekondi Coast, Ghana. *Geography Journal, 2016*, 9 pages. Retrieved from https://doi.org/10.1155/2016/1868936

31. Dadzie-Paintsil, E., & Mensah, J. V. (2022). Effects of urbanization on coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana. *Indo Pacific Journal of Ocean Life, 6*(2), 94-105. Retrieved from https://smujo.id/ol/article/view/12783

32. Dadzie-Paintsil, E., & Mensah, J. V. (2022). Effects of urbanization on coastal wetlands in the Sekondi-Takoradi Metropolis, Ghana. *INDO PAC J OCEAN LIFE, 6*(2), 94-105. doi:10.13057/oceanlife/o060205

33. Danso, S. Y., & Addo, I. Y. (2017). Coping strategies of households affected by flooding: A case study of Sekondi-Takoradi Metropolis in Ghana. *Urban Water Journal, 14*(5), 539-545. doi:10.1080/1573062X.2016.1176223

34. Delvaux, M. B., & Brahy, V. (2001). Mineral Soils conditioned by a Wet (Sub)Tropical Climate. In I. I. Paul Driessen [Wageningen Agricultural Univ. (Ed.), *Lecture notes on the major soils of the world.* FAO. Retrieved from https://www.fao.org/3/Y1899E/y1899e08a.htm

35. Department of Environment, Forestry and Fisheries. (2020). *National Climate Risk and Vulnerability (CRV) Assessment Framework summary document.* Pretoria: South Africa: Department of Environment, Forestry and Fisheries (DEFF).

36. Diaz, D., & Moore, F. (2017). Quantifying the economic risks of climate change. *Nature Climate Change, 7*, 774–782. doi:https://doi.org/10.1038/nclimate3411

37. Doku, B. N., Chen, S., Alhassan, E. H., Abdullateef, Y., & Rahman, M. M. (2018). Fisheries resources of Ghana: present status and future direction. *International Journal of Fisheries and Aquatic Research, 3*(4), 35-41. Retrieved from https://www.researchgate.net/publication/333566631_Fisheries_resources_of_Ghana_present

38. _status_and_future_direction

39. Duguma, L., Bah, A., Muthee, K., Carsan, S., McMullin, S., & Minang, P. (2022). *Drivers and Threats Affecting Mangrove Forest Dynamics in Ghana and The Gambia.* Women Shellfishers and Food Security Project. World Agroforestry (ICRAF), Nairobi, Kenya and Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island. Narragansett, RI, USA. Retrieved from https://www.worldagroforestry.org/publication/drivers-and-threats-affecting-mangrove-forest-dynamics-ghana-and-gambia

40. Eduful, A. K., & Hooper, M. (2019). Urban migration and housing during resource booms: The case of Sekondi-Takoradi, Ghana. *Habitat International, 93*(102029). doi:doi.org/10.1016/j.habitatint.2019.102029

41. Energy Commission. (2022). *2022 Energy Statistics*. Retrieved from http://www.energycom.gov.gh/files/2022%20Energy%20Statistics.pdf

42. Fall, B., Correa, J. B., & Sarr, S. (2011). *Guide Methodologique Pour L�Evaluation de la Vulnérabilité au Changement Climatique au Niveau Communautaire (Zones Côtières).* Consultant report by Environnement-Développement du Tiers Monde (ENDA). Dakar, Senegal: USAID/COMFISH project.

43. Fant, C., Boehlert, B., Strzepek, K., Larsen, P., White, A., Gulati, S., . . . Martinich, J. (2020). Climate change impacts and costs to US electricity transmission and distribution infrastructure.

44. *Energy*. doi:https://doi.org/10.1016/j.energy.2020.116899

45. Fiave, R. (2017). Sekondi-Takoradi as an Oil City. *Geography Research Forum, 37*, 61-79. Retrieved from https://www.researchgate.net/publication/327546305_Sekondi-Takoradi_as_an_Oil_City

46. Fiave, R. E. (2017). Sekondi-Takoradi as an oil city. *Geography Research Forum, 37*(2), 61-79.

47. Retrieved from https://www.researchgate.net/publication/327546305_Sekondi-Takoradi_as_an_Oil_City

48. Field, C., Barros, V., Mach, K., Mastrandrea, M., Aalst, M. v., Adger, W., . . . Yohe, G. (2014).

49. Technical summary. In C. Field, V. Barros, D. Dokken, K. Mach, M. Mastrandrea, T. Bilir, . . . L.L.White (Eds.), *Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 35-94). Cambridge, United Kingdom and New York, NY, USA,: Cambridge University Press. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-TS_FINAL.pdf

50. Finegold, C., Gordon, A., Mills, D., Curtis, L., & Pulis, A. (2010). *Western region fisheries sector review. World Fish Center. USAID Integrated Coastal and Fisheries Governance Initiative for the Western Region, Ghana.* Narragansett: University of Rhode Island, United States.

51. Retrieved from https://www.fao.org/fishery/en/openasfa/afc21805-5f8d-4059-afd3-a0a3d2401f40

52. Freduah, G., Fidelman, P., & Smith, T. (2017). The impacts of environmental and socio-economic stressors on small scale fisheries and livelihoods of fishers in Ghana. *Applied Geography, 89*(2017), 1-11. doi:https://doi.org/10.1016/j.apgeog.2017.09.009

53. Fugu, M. (2022, 03 25). Effect of illegal sand winning: Shutdown of Dalun water treatment plant imminent. *Graphic Online*. Retrieved from https://www.graphic.com.gh/news/general-news/effect-of-illegal-sand-winning-shutdown-of-dalun-water-treatment-plant-imminent.html

54. Ghana Forestry Commission. (2021). *Ghana national land use map.* Retrieved from https://ghana-national-landuse.knust.ourecosystem.com/interface/

55. Ghana Highway Authority. (2023). *Road Network*. Retrieved from Ghana Highway Authority: https://www.highways.gov.gh/road_net

56. Ghana Statistical Service. (2014). *2010 Population & Housing Census: District Analytical Report - Sekondi-Takoradi Metropolitan.* Accra: Ghana Statistical Service (GSS). Retrieved from https://www2.statsghana.gov.gh/docfiles/2010_District_Report/Western/STMA.pdf

57. Ghana Statistical Service. (2014). *Migration in Ghana - 2010 Population & Housing Census Report.*

58. Accra: Ghana Statistical Service. Retrieved from https://www.statsghana.gov.gh/gssmain/fileUpload/pressrelease/Migration%20in%20Ghana.p df

59. Ghana Statistical Service. (2015). *Ghana Poverty Mapping Report.* Accra: 2015 Ghana Statistical Service. Retrieved from https://www2.statsghana.gov.gh/docfiles/publications/POVERTY%20MAP%20FOR%20GHAN A-05102015.pdf

60. Ghana Statistical Service. (2022a). *Ghana 2021 Population and Housing Census: General Report Volume 3k, Housing Characteristics.* Accra: Ghana Statistical Service (GSS). Retrieved from https://census2021.statsghana.gov.gh/gssmain/fileUpload/reportthemesub/Volume%203K_Ho using%20Characteristics_240222.pdf

61. Ghana Statistical Service. (2022b). *Ghana 2021 Population and Housing Census: General Report District Tables Volume 3E, Economic Activity District.* Accra: Ghana Statistical Service (GSS). Retrieved from https://census2021.statsghana.gov.gh/subreport.php?readreport=MTIxNDAwNTMzNy4zMTk= &General-Report-District-Tables

62. Ghana Statistical Services. (2021). *Ghana 2021 Population and Housing Census (PHC) - Volume 3A: Population of Regions and Districts.* Accra: Ghana Statistical Services. Retrieved from https://census2021.statsghana.gov.gh/dissemination_details.php?disseminatereport=MjYzOT E0MjAuMzc2NQ==&Publications#

63. Global Commission on Adaptation. (2019). *Adapt Now: A Global Call for Leadership on Climate Resilience.* Rotterdam and Washington, DC: Global Commission on Adaptation. Retrieved from https://gca.org/reports/adapt-now-a-global-call-for-leadership-on-climate-resilience/

64. Global Facility for Disaster Reduction and Recovery (GFDRR) . (2022). *Think Hazard Ghana*.

65. Retrieved from ThinkHazard! : https://thinkhazard.org/en/report/94-ghana

66. Graziosi, I., Tembo, M., Kuate, J., & Muchugi, A. (2020). Pests and diseases of trees in Africa: A growing continental emergency. *Plants, People, Planet, 2*(1), 14-28. doi:https://doi.org/10.1002/ppp3.31

67. Habib, Y., & Mensah, C. J. (2020). Spatial Traceability of Irrigation Sources for Urban Agricultural Hotspots in Ghana. *Elixir Environment & Forestry, 140*, 54190-54194. Retrieved from https://www.academia.edu/43563935/Spatial_Traceability_of_Irrigation_Sources_for_Urban_A gricultural_Hotspots_in_Ghana

68. Hasselberg, A. E., Aakre, I., Scholtens, J., Overå, R., Kolding, J., Bank, M. S., . . . Kjellevold, M. (2020). Fish for food and nutrition security in Ghana: Challenges and opportunities. *Global Food Security, 26*(100380). doi:https://doi.org/10.1016/j.gfs.2020.100380.

69. He, C., Breuning-Madsen, H., & Awadzi, T. W. (2007). Mineralogy of dust deposited during the Harmattan season in Ghana. *Geografisk Tidsskrift, 107*(1), 9-15. doi:10.1080/00167223.2007.10801371

70. Horwich, R., & Stevens, H. (2013). *Report from Community Conservation on Primates in the Western Region.* Coastal Resources Center, University of Rhode Island. USAID Integrated Coastal and Fisheries Governance Program for the Western Region of Ghana. Retrieved from https://www.crc.uri.edu/download/GH2009DC3P002_Horwich_508.pdf

71. IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* (V. Masson-Delmotte, P. Zhai, A. Pirani, S. Connors, C. Péan, S. Berger, . . . B. Zhou, Eds.) Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi:https://dx.doi.org/10.1017/9781009157896

72. Jha, A., Lamond, J., Proverbs, D., Bhattacharya-Mis, N., Lopez, A., Papachristodoulou, N., . . .

73. Century, R. B. (2012). *Cities and Flooding: A guide to integrated urban flood risk management for the 21st.* The World Bank, GFDRR. Retrieved from https://www.researchgate.net/publication/272793713_Cities_and_Flooding_A_guide_to_integr ated_urban_flood_risk_management_for_the_21st_Century

74. LDC Expert Group. (2012). *NATIONAL ADAPTATION PLANS: Technical guidelines for the national adaptation plan process.* Bonn, Germany: United Nations Climate Change Secretariat.

75. Maks Publications & Media Services. (2006). *Ghana Districts: A repository of all Local Assemblies in Ghana.* (A Public-Private Program between Min of Local Government, Decentralisation & Rural Dev. and Maks Publications & Media Services) Retrieved from Ghana Districts: Sekondi Takoradi Metropolitan Assembly: https://www.ghanadistricts.com/Home/District/212

76. Martin, S. (2012). *No-regret low-regret and win-win adaptation actions.* climateXchange.

77. Mattah, P. A., Futagbi, G., & Mattah, M. M. (2018). Awareness of environmental change, climate variability, and their role in prevalence of mosquitoes among urban dwellers in southern Ghana. (S. Akiba, Ed.) *Journal of environmental and public health*, 9 pages. doi:https://doi.org/10.1155/2018/5342624

78. Mattah, P. A., Futagbi, G., Amekudzi, L. K., & Mattah, M. M. (2020). Climate variations, urban solid waste management and possible implications for Anopheles mosquito breeding in selected cities of coastal Ghana. *West African Journal of Applied Ecology, 28*(1), 21 – 34. Retrieved from https://www.ajol.info/index.php/wajae/article/view/199537

79. McSweeney, C., New, M., & Lizcano, G. (2012). *UNDP climate change country profiles: Ghana.*

80. Retrieved from https://www.geog.ox.ac.uk/research/climate/projects/undp-cp/

81. Menk, L., Terzi, S., Zebisch, M., Rome, E., Lückerath, D., Milde, K., & & Kienberger, S. (2022).

82. Climate Change Impact Chains: A Review of Applications, Challenges, and Opportunities for Climate Risk and Vulnerability Assessments. *Weather, Climate, and Society*, 619-636. doi:https://doi.org/10.1175/wcas-d-21-0014.1

83. Mensah, M., Koranteng, K., Bortey, A., & Yeboah, A. (2006). *The State of World Fisheries from a Fishworker Perspective: The Ghanaian Situation.* International Collective in Support of Fishworkers. Retrieved from https://aquadocs.org/handle/1834/18209

84. Ministry of Foreign Affairs of the Netherlands. (2019). *Climate Change Profile: Ghana.* The Hague: Ministry of Foreign Affairs of the Netherlands. Retrieved from https://reliefweb.int/report/ghana/climate-change-profile-ghana

85. Murken, L., Gornott, C., Aschenbrenner, P., Chemura, A., Hattermann, F., Koch, H., . . . Yalew, A. W. (2019). *Climate Risk Analysis for Identifying and Weighing Adaptation Strategies in Ghana's Agricultural Sector.* Potsdam, Germany: Potsdam Institute for Climate Impact Research (PIK) . Retrieved from https://www.adaptationcommunity.net/publications/climate-risk-analysis-for-identifying-and-weighing-adaptation-strategies-in-ghanas-agricultural-sector/

86. National Climate Change Adaptation Research Facility (NCCARF) . (n.d.). *CoastAdapt: Assess risks and impacts*. Retrieved from CoastAdapt: https://coastadapt.com.au/how-to-pages/how-to-conduct-a-climate-change-risk-assessment

87. Nduhuura, P., Garschagen, M., & Zerga, A. (2021). Impacts of Electricity Outages in Urban Households in Developing Countries: A Case of Accra, Ghana. *Energies, 14*. doi:10.3390/en14123676

88. Norman, B., Webb, B., Steffen, W., O'Donnell, T., Sloan, T., Weir, B., & Williams, J. (2014). *Climate Adaptation Sector Review: Informing the Future Direction for the ACT and Region.* Canberra: Canberra Urban and Regional Futures. Retrieved from https://www.researchgate.net/publication/268747271_Climate_Adaptation_Sector_Review_Inf orming_the_Future_Direction_for_the_ACT_and_Region

89. Nunoo, F. K., & Agyekumhene, A. (2022). Mangrove Degradation and Management Practices along the Coast of Ghana. *Agricultural Sciences, 13*(10), 1057-1079. doi:10.4236/as.2022.1310065

90. Odjer-Bio, N., Belford, E., & Ansong, M. (2015). What is happening to our Lagoons? The example of Butuah Lagoon in Ghana. *International Journal of Energy and Environmental Engineering, 6*, 183–193. doi:https://doi.org/10.1007/s40095-015-0165-1

91. Okyere, I. (2011). Comparative ecological assessment of biodiversity of fish communities in three coastal wetland systems in Ghana. *European Journal of Experimental Biology, 1*, 178-188. Retrieved from https://www.researchgate.net/publication/261875842_Comparative_ecological_assessment_o f_biodiversity_of_fish_communities_in_three_coastal_wetland_systems_in_Ghana

92. Olympio, G. F., & Amos-Abanyie, S. (2014). Effects of shoreline erosion on infrastructure development along the coastal belt of Ghana: Case of Nkontompo community. *Journal of Science and Technology (Ghana), 33*(3 (2013)), 39-50. doi:10.4314/just.v33i3.5

93. Ovadia, J. S., & Graham, E. (2022). 3 The Resource Curse and Limits of Petro-Development in Ghana's 'Oil City': How Oil Production Has Impacted Sekondi-Takoradi. In N. Andrews, J. A. Grant, & J. S. Ovadia (Eds.), *Natural Resource-Based Development in Africa: Panacea or Pandora's Box?* (pp. 59-78). Toronto: University of Toronto Press. doi:https://doi.org/10.3138/9781487547684-005

94. Owusu, G., & Afutu-Kotey, R. L. (2010). Poor Urban Communities and Municipal Interface in Ghana: A Case Study of Accra and Sekondi-Takoradi Metropolis. *African Studies Quarterly, 12*.

95. Retrieved from https://www.researchgate.net/publication/265290209_Poor_Urban_Communities_and_Munici pal_Interface_in_Ghana_A_Case_Study_of_Accra_and_Sekondi-Takoradi_Metropolis

96. Owusu, K., Yankson, P. W., Asiedu, A. B., & Tutu-Benefor, D. (2019). Climate change impacts on two coastal metropolitan areas in Ghana (Chapter 5). In S. N. Codjoe, & D. B. Dovie, *Climate Change in Ghana: The human Dimension* (pp. 77-94). Accra: Afram Publication (Ghana) Limited.

97. Pwamanng, J. A., Appah-Sampong, r. E., & Oppong-Boadi, K. (2020, May). Ghana's Fourth National Communication to the United Nations Framework Convention on Climate Change. (L. Mensah, Ed., & D. D. Benefoh, Compiler) Ghana: Environmental Protection Agency (EPA). Retrieved from https://unfccc.int/sites/default/files/resource/Gh_NC4.pdf

98. Pwamanng, J. A., Appah-Sampong, r. E., & Oppong-Boadi, K. (2020, mAY). Ghana's Fourth National Communication to the United Nations Framework Convention on Climate Change. (L. Mensah, Ed., & D. D. Benefoh, Compiler) Ghana: Environmental Protection Agency (EPA). Retrieved from https://unfccc.int/sites/default/files/resource/Gh_NC4.pdf

99. Ray, P. A., & Brown, C. M. (2015). *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework.* Washington, DC: The World Bank Group. doi:10.1596/978-1-4648-0477-9

100. Republic of Ghana Ministry of Fisheries and Aquaculture Development. (2015). Fisheries management plan of Ghana, a national policy for the management of the marine fisheries sector 2015 – 2019. Ghana. Retrieved from https://www.fao.org/faolex/results/details/en/c/LEX-FAOC160291/

101. Rode, A., Carleton, T., Delgado, M., & al., e. (2021). Author Correction: Estimating a social cost of carbon for global energy consumption. *Nature, 600*, E17. doi:https://doi.org/10.1038/s41586-021-04185-9

102. Samuel Yaw Danso, I. Y. (2017). Coping strategies of households affected by flooding: A case study of Sekondi-Takoradi Metropolis in Ghana. *Urban Water Journal, 14*(5), 539-545. Retrieved from https://doi.org/10.1080/1573062X.2016.1176223

103. Sarwar, M. B., Holmes, R., Korboe, D., Afram, A., & Salomon, H. (2022). *Understanding vulnerability and exclusion in Ghana,.* London: ODI. Retrieved from https://cdn.odi.org/media/documents/V_and_E_study_Ghana_8.8.22.pdf

104. Sekondi Takoradi Metropolitan Assembly. (2022). *Sekondi-Takoradi Metropolitan Assembly IAbout Us*.

105. Retrieved from Sekondi-Takoradi Metropolitan Assembly: https://stma.gov.gh/about-us Sekondi-Takoradi Metropolitan Assembly. (2020). *Composite Budget for 2022-2023.* Sekondi-

106. Takoradi. Retrieved from https://mofep.gov.gh/sites/default/files/composite-budget/2020/WR/Sekondi-Takoradi.pdf

107. Siabi-Mensah, M. (2022, 09 24). Sekondi-Takoradi Metropolitan Assembly plants fruit trees at Apremdo barracks. *Ghana News Agency*. Retrieved from https://gna.org.gh/2022/09/sekondi-takoradi-metropolitan-assembly-plants-fruit-trees-at-apremdo-barracks/

108. Stanturf, J. A., Warren, M. L., Charnley, S., Polasky, S. C., Goodrick, S. L., Armah, F., & Nyako, Y. A. (2011). *Ghana climate change vulnerability and adaptation assessment.* Washington, DC:: USAID. Retrieved from https://www.climatelinks.org/resources/ghana-climate-change-vulnerability-and-adaptation-assessment

109. STMA Metro Planning and Coordinating Unit. (2014). *Medium-Term Development Plan [2014-2017] (Final Draft).* Sekondi-Takoradi Metropolitan Assembly. Retrieved from https://new-ndpc-static1.s3.amazonaws.com/CACHES/PUBLICATIONS/2016/04/16/WR_Sekondi-Takoradi+Metro_2014-2017+MTDP.pdf

110. STMA Metro Planning and Coordinating Unit. (2021). *Medium-Term Development Plan [2022-2025].*

111. Sekondi-Takoradi Metropolitan Assembly. Retrieved from https://stma.gov.gh/documents/STMA%20Final%20Submitted%20MTDP%202022%202025.p df

112. Tanner, T., Mensah, A., Lawson, E. T., Gordon, C., Godfrey-Wood, R., & Cannon, T. (2014). Political economy of climate compatible development: artisanal fisheries and climate change in Ghana. *IDS Working Papers,, 2014*(446), 1-30. doi:https://doi.org/10.1111/j.2040-0209.2014.00446.x

113. The World Bank Group. (2009). *Identifying Appropriate Adaptation Measures to Climate Change. Guidance Notes: Mainstreaming Adaptation to Climate Change in Agriculture and Natural Resources Management Projects.* Washington, USA: The World Bank Group.

114. The World Bank Group. (2019). *Home | West Africa Coastal Areas Management Programme (WACA)*.

115. Retrieved from West Africa Coastal Areas Management Programme: https://www.wacaprogram.org/

116. The World Bank Group. (2021a). Climate Risk Profile: Ghana. Retrieved from https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15857-WB_Ghana%20Country%20Profile-WEB.pdf

117. The World Bank Group. (2021b). *Ghana - Climatology*. Retrieved from Climate Change Knowledge Portal: https://climateknowledgeportal.worldbank.org/country/ghana/climate-data-historical

118. The World Bank Group. (2021c). *Ghana - Mean Projections Expert*. Retrieved from Climate Change Knowledge Portal: https://climateknowledgeportal.worldbank.org/country/ghana/climate-data-projections

119. The World Bank Group. (2021d). *Ghana - Sea Level Rise*. Retrieved from Climate Change Knowledge Portal: https://climateknowledgeportal.worldbank.org/country/ghana/impacts-sea-level-rise

120. Triple Line Consulting Limited. (2022). *CIG Ghana: Flood risk mapping and modelling report .* IMC Worldwide.

121. Twerefou, D., Chinowsky, P., Adjei-Mantey, K., & Strzepek, N. (2015). The Economic Impact of Climate Change on Road Infrastructure in Ghana. *Sustainability , 7*, 11949-11966. doi:https://doi.org/10.3390/su70911949

122. U. S. Census Bureau. (2023). *Subnational Population Data by Geographic Area*. Retrieved from Census.gov: https://www.census.gov/geographies/mapping-files/time-series/demo/international-programs/subnationalpopulation.html

123. UKCIP. (2011). *Identifying adaptation options (AdOpt).* Retrieved from UKCIP. Oxford: https://www.ukcip.org.uk/wp-content/PDFs/ID_Adapt_options.pdf

124. UKCIP. (2013a, Julho 30). *Local Climate Impacts Profile (LCLIP) spreadsheet*. Retrieved 2020, from https://www.ukcip.org.uk/wp-content/LCLIP/lclip-spreadsheet-macros-notenabled.xls

125. UKCIP. (2013b, Julho 30). *LCLIP Spreadsheet guidance notes*. Retrieved 2020, from https://www.ukcip.org.uk/wp-content/LCLIP/LCLIP-spreadsheet_notes.doc

126. UNDRR and CIMA . (2019). *Ghana Disaster Risk Profile.* Nairobi: United Nations Office for Disaster Risk Reduction (UNDRR) and CIMA Research Foundation. Retrieved from https://www.undrr.org/publication/disaster-risk-profile-ghana

127. UNEP, IEMP & IISD. (2018). *Adaptation, Livelihoods and Ecosystems Planning Tool: User Manual. Version 1.0.* Retrieved from https://www.iisd.org/system/files/publications/alive-tool-manual-web.pdf

128. UNESCO-IOC. (2021). Lessons learnt and best practices of managing coastal risk from local communities' perspectives. (A. I.-C.-I. Tiago Garcia, Ed.) Paris: UNESCO - Intergovernmental Oceanographic Commission (IOC). Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000378081

129. University of Oxford . (2023). *Nature-Based Solutions Initiative | What are Nature-based Solutions?*

130. Retrieved from Nature-Based Solutions Initiative: https://www.naturebasedsolutionsinitiative.org/what-are-nature-based-solutions/

131. USAID. (2017). Climate Change Risk Profile – Ghana (Fact Sheet). Retrieved from https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_Climate%20Cha nge%20Risk%20Profile%20-%20Ghana.pdf

132. USAID. (2019). Climate Risk Profile – West Africa (Fact sheet). Retrieved from https://www.climatelinks.org/sites/default/files/asset/document/West_Africa_CRP_Final.pdf

133. Volta River Authority. (2023). *Volta River Authority | Profile of VRA*. Retrieved from Volta River Authority: https://vra.com/about_us/profile.php

134. WHO. (2015). *Climate and health country profile- 2015 Ghana.* Geneva: WHO. Retrieved from https://www.who.int/publications/i/item/WHO-FWC-PHE-EPE-15.08

135. World Population Review. (2023). *Sekondi Takoradi Population 2023*. Retrieved from 2023 World Population by Country (Live): https://worldpopulationreview.com/world-cities/sekondi-takoradi-population

136. WorldPop Spatial Data Infrastructure. (2022). *WorldPop :: Ghana (GHA)*. Retrieved from WorldPop: https://hub.worldpop.org/geodata/country?iso3=GHA

137. WWF. (2020). *Water Risk Filter: Country Overview - Ghana.* Retrieved from https://wateractionhub.org/media/files/2020/08/19/Country_Profile_85.pdf

138. www.meteoblue.com. (2022). *Simulated historical climate & weather data for Sekondi-Takoradi*.

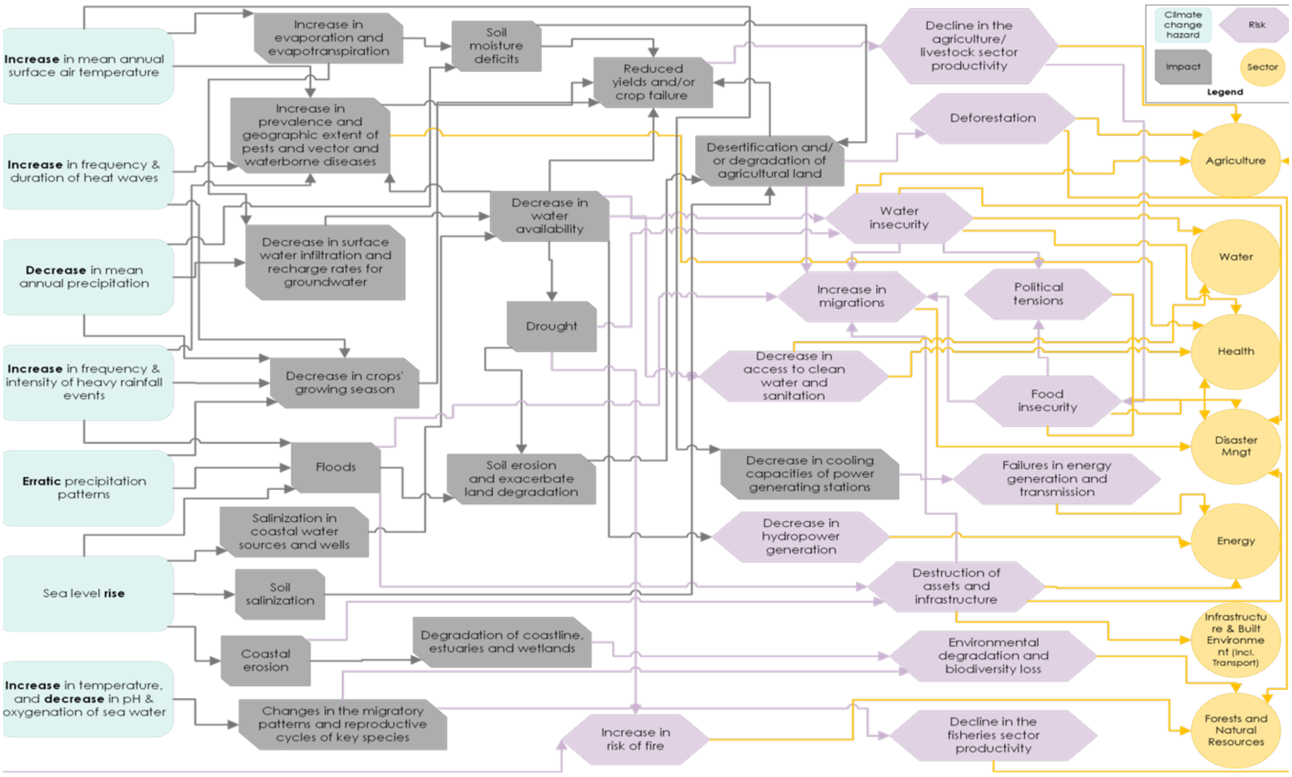
139. Retrieved from meteoblue: https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/sekondi-takoradi_ghana_2295458

140. Yankson, P., Gough, K., Esson, J., & Amankwaa, E. (2017). Spatial and social transformations in a secondary city: the role of mobility in Sekondi-Takoradi, Ghana. *Geografisk Tidsskrift-Danish Journal of Geography, 117*, 1-11. doi: 10.1080/00167223.2017.1343672

141. Zebisch, M., Schneiderbauer, S., Fritzsche, K., Bubeck, P., Kienberger, S., Kahlenborn, W., . . . Below, T. (2021, February). The vulnerability sourcebook and climate impact chains – a standardised framework for a climate vulnerability and risk assessment. *International Journal of Climate Change Strategies and Management*, pp. ahead-of-print. doi:10.1108/IJCCSM-07-2019-0042

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 impact MMDA level in Ghana



Appendix B I Stakeholder Engagement

B1 I Stakeholders List – Sekondi-Takoradi

Session One

1. The Presiding Member, STMA, Sekondi
2. The Director, Ministry of Food and Agriculture, STMA, Sekondi
3. The Director, Physical Planning Department, STMA, Sekondi
4. The Director, Development Planning Department, STMA, Sekondi
5. The Director, Works Department, STMA, Sekondi
6. The Director, National Disaster Management Organisation, STMA, Sekondi
7. The Director, Environmental Health Department, STMA, Sekondi
8. The Director, Ministry of Health, STMA, Sekondi
9. The Regional Director, Ghana Education Service, Sekondi

Session Two

10. The Director, Coastal Development Authority, Sekondi
11. The Ankobra Basin Officer, Water Resources Commission, Abosso
12. The Regional Director, Fisheries Commission, Takoradi
13. The Regional Director, Forestry Commission, Takoradi
14. The Director, Ghana National Canoe Fishermen Council, Takoradi
15. The Director, National Fish Processors and Traders Association, Takoradi
16. The Director, Hen Mpoano, Adiembra
17. The Director, Friends of the Nation, Adiembra
18. The Director, African Women International, Takoradi
19. The Director, Ghana Federation of Disability Organisation, Takoradi
20. The Regional Director, Environmental Protection Agency, Sekondi

B2 I Stakeholders List – Workshops held in Accra

7/December/2022

No.	Name	Institution
26.	Abena A. Adu	LUSPA
27.	Patience Agyekum	SYND
28.	Francisca Martey	GMET
29.	George Yorke	WaterAid
30.	Joy Hesse Ankomah	EPA-HSU
31.	Elliot Ansah	GSS
32.	Miriam Bafowaa opoku	DOR
33.	Antwi – B. Amoah	EPA
34.	Bob Manteaw	UG
35.	Eric Afornorpe	MLGDRD
36.	Evelyn Addor	Ecocare Ghana
37.	Carl Osei	GHS
38.	Joyce Gyeke	GBC
39.	David Aidoo	WaterAid
40.	Mumuni Abu	RIPS, UG
41.	Bernard Asante	VAL-Ghana
42.	Robert Mensah	MOF
43.	Foster A. Gyamfi	MOF
44.	Jonathan Gokah	Kasa Gh
45.	Joycelyn Smith	MOF
46.	Lydia Kukua Asamoah	GNA
47.	Isaac Kwabena Danso	EPA
48.	Kumi Sarfo Obed	EPA
49.	Marilyn Christian	EPA
50.	Emmanuel. A. Oduro	EPA

8/December/2022

No.	Name	Institution
51.	Abena A. Adu	LUSPA
52.	Patience Agyekum	SYND
53.	Francisca Martey	GMET
54.	George Yorke	WaterAid
55.	Joy Hesse Ankomah	EPA-HSU
56.	Elliot Ansah	GSS
57.	Miriam Bafowaa opoku	DOR
58.	Monique Cranna	ZUTARI
59.	Antwi – B. Amoah	EPA
60.	Bob Manteaw	UG
61.	Eric Afornorpe	MLGDRD
62.	Evelyn Addor	Ecocare Ghana
63.	Naa Adaku Palm	LUSPA
64.	Ishomon Foli	VALD- Ghana
65.	MaryJane Eunchill	PMU-NAP
66.	Joyce Gyeke	GBC
67.	Isabel Andam	SYND
68.	Solomon Yamoaa	YNREG
69.	Ali M. Katu	GAIP
70.	James Oppong Otoo	NADMO
71.	Angela Kwashie	UNCDF
72.	Robert Mensah	MOF
73.	Foster A. Gyamfi	MOF
74.	Jonathan Gokah	Kasa Gh
75.	Jocelyn Smith	MOF
76.	Lydia Kukua Asamoah	GNA
77.	Isaac Kwabena Danso	EPA
78.	Kumi Sarfo Obed	EPA
79.	Marilyn Christian	EPA
80.	Emmanuel. A. Oduro	EPA

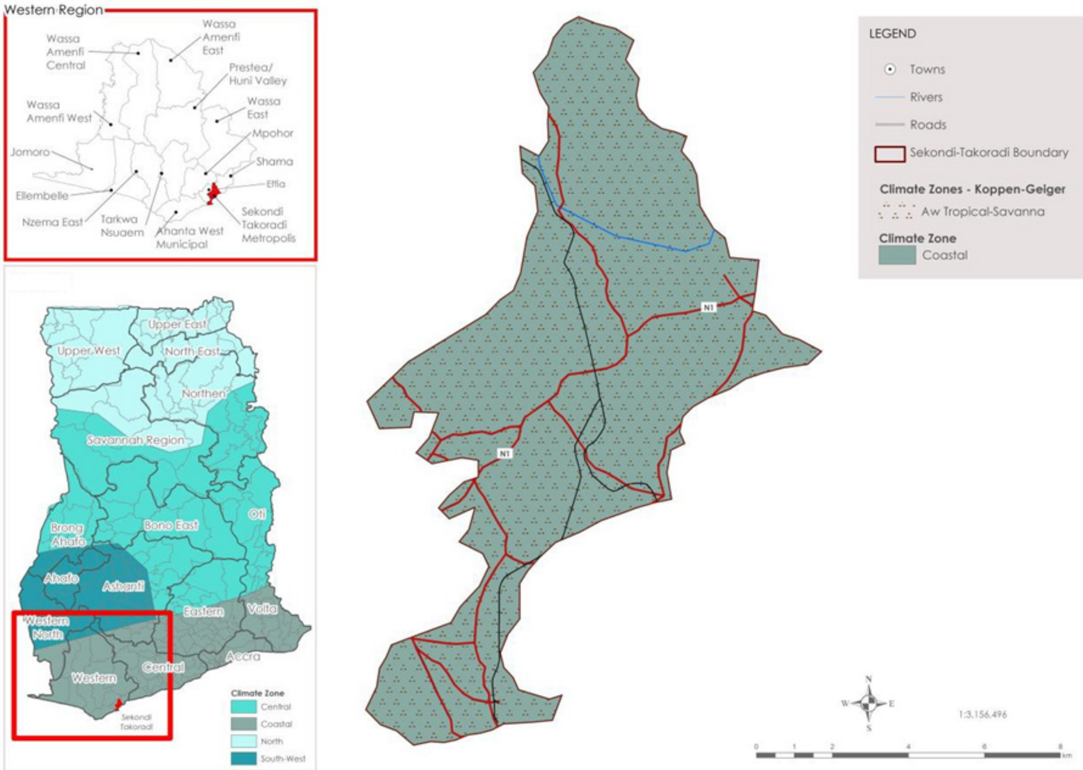
C1 I Location and Climate

Sekondi-Takoradi Metropolitan Assembly is one of the 14 districts in the Western Region, in Ghana, with Sekondi as the administrative capital. The Twin-City of Sekondi-Takoradi is the capital of the Western Region. The Metropolis is a port city on the Gulf of Guinea, located at the south-eastern part of the Western Region, and has a total land size of about 119 km^2. STMA is bordered to the north by Mpohor District, Shama District to the east, Effia-Kwesimintsim Municipal to the west and south by the Gulf of Guinea (Sekondi Takoradi Metropolitan Assembly, 2022). The location of STMA is shown in Figure C. .

The Metropolis is of varied landscape, the coastline has capes and bays, which have been largely eroded. The central area of STMA has an altitude of 6m above sea level which is low lying. The low-lying areas in the Metropolis are interspersed with ridges and hills ranging from 30m – 60m high. The general low-lying nature of the topography especially in the coastal areas is a key challenge as heavy rains results in frequent flooding and as a result increase in pressure on storm drain infrastructure for vantage points of the Metropolis to avert flooding (STMA Metro Planning and Coordinating Unit, 2021).

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 what to future climate change under the different global emission scenarios. Sekondi-Takoradi Metropolitan Assembly is located in the Coastal Climate Zone

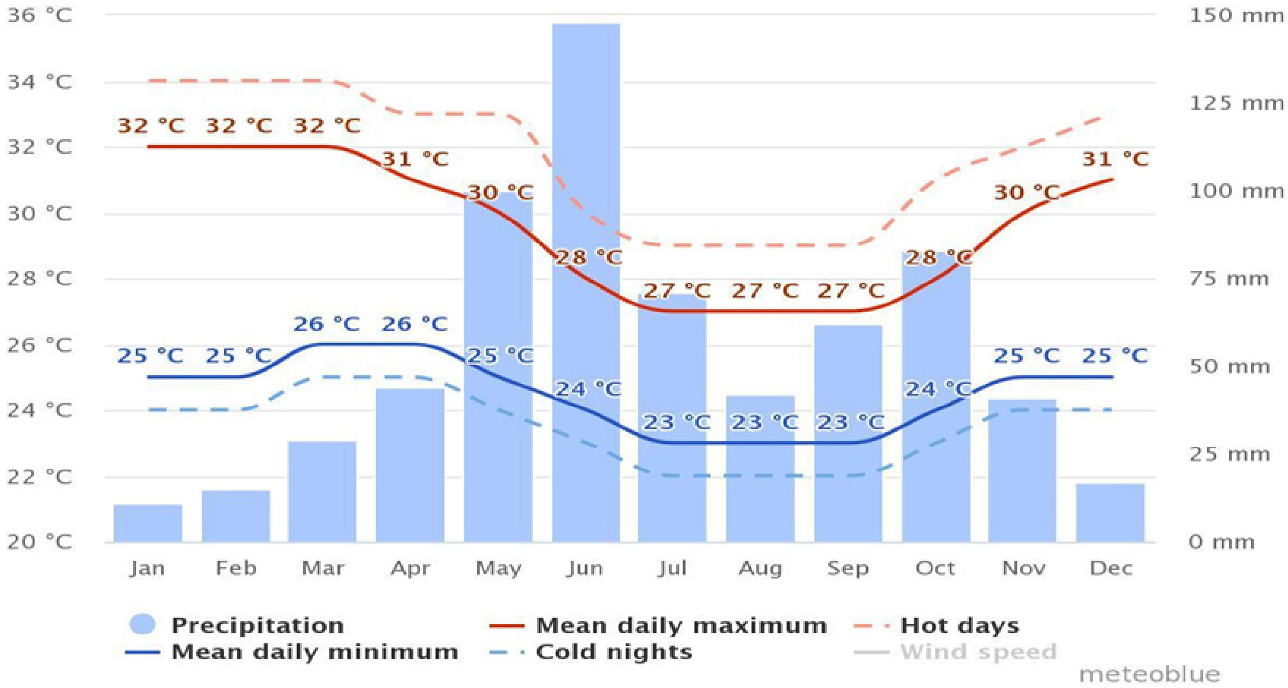
Figure C. 1 I Location and climate of STMA



According to the Köppen-Geiger climate classification, STMA has a tropical savanna climate, Aw (Tropical Savanna Climate). Over the course of the year, the temperature typically varies from 23°C to 31°C and is rarely below 22°C or above 33°C. The hottest month of the year in Sekondi-Takoradi is March, with an average high of 31°C and low of 26°C. The coldest month of the year in Sekondi-Takoradi is August, with an average low of 23°C and high of 27°C.

The mean annual rainfall is about 1 380mm and covers an average of 122 rainy days, with the most precipitation occurring in June with 25.1 days with 333 mm of precipitation, and the least precipitation occurring in January with 5.5 days with an average of 25.4 mm. During most months of the year, there is significant rainfall in Sekondi-Takoradi and there is only a short dry season, which is hot and partly cloudy. The wet season in Sekondi-Takoradi is warm and mostly cloudy, and it is humid year-round. The climate diagram for the average temperature and precipitation for STMA 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 STMA



Source: (www.meteoblue.com, 2022)

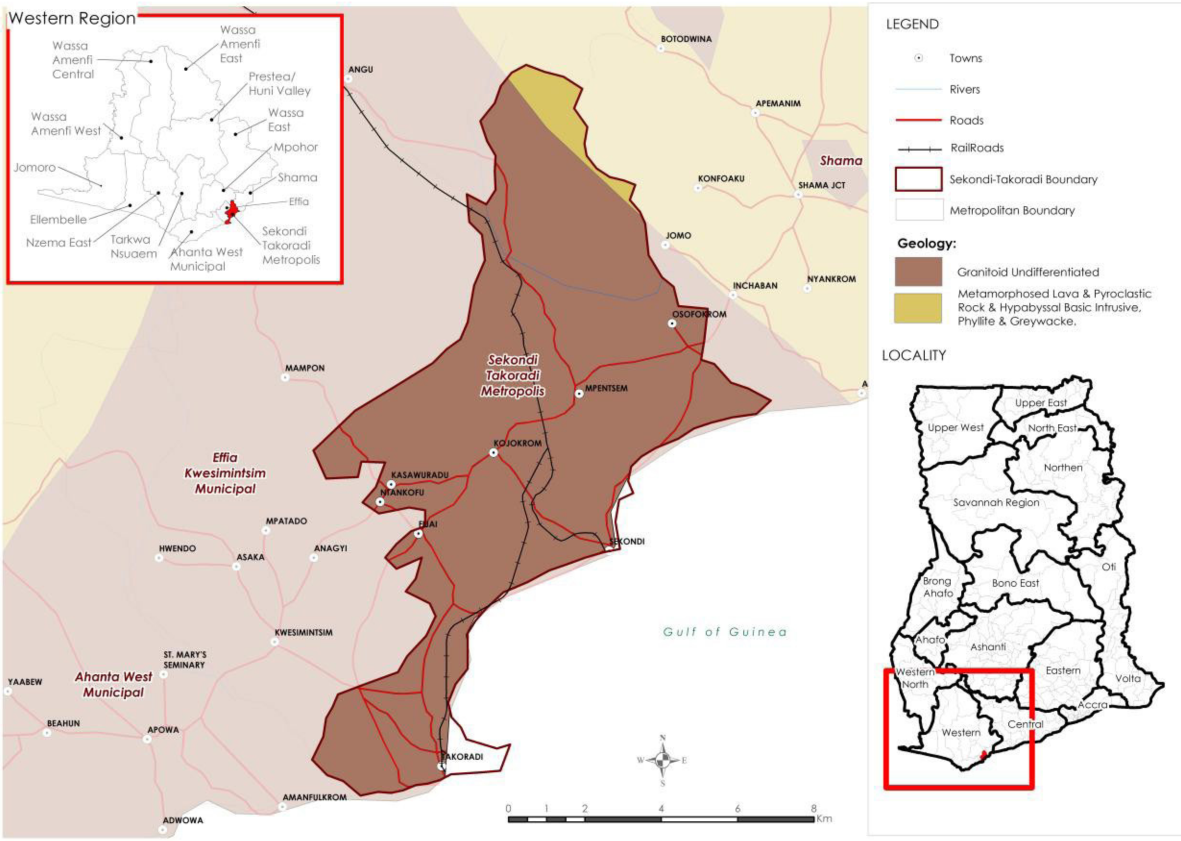
C2 I Natural Environment

Geology, Geomorphology and Soils

Geologically, shales and sandstones are the major rock types in STMA. These rocks are found on hard basement of granites, gneiss and schists. The landform of the coastline has been influenced by the faulting system. The water table is high and has a relatively high salt content on groundwater. This situation calls for adequate soil investigation before embarking on major infrastructure development. Most of these stone deposits are mainly found in Diabenekrom, Essipon, Kojokrom and Butumajebu (STMA Metro Planning and Coordinating Unit, 2021).

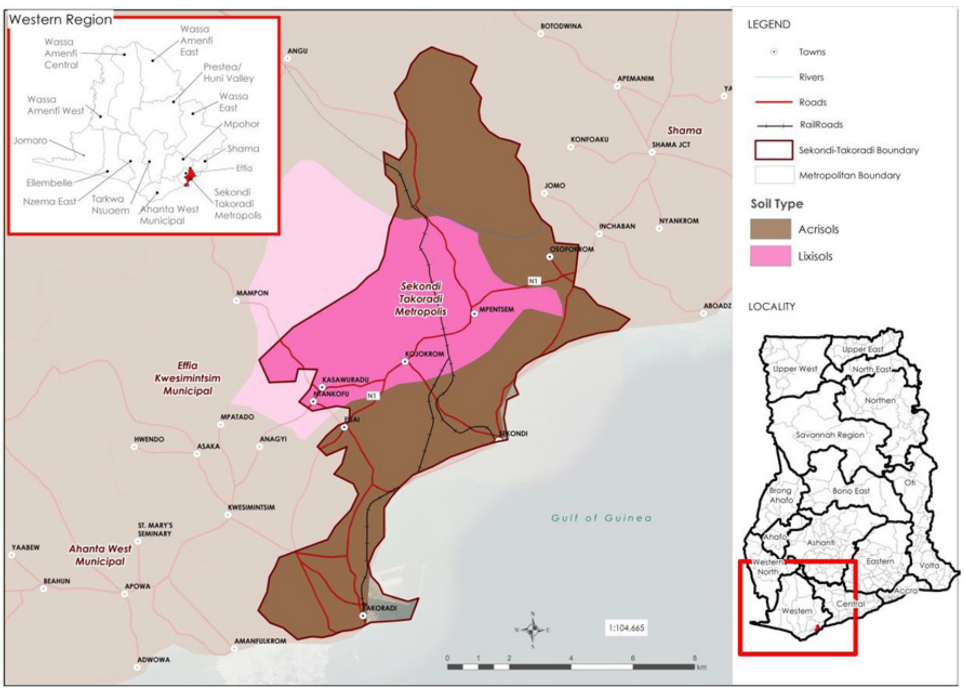
Ghana's coast is sub-divided into three zones, namely Western, Central and Eastern based on the geomorphology (Ly, 1980; Wellens-Mensah et al., 2002). The West Coast, where STMA is located is the smallest with 95 km of shoreline from the estuary of the Ankobra River to the border with Côte d'Ivoire. The West coast comprises flat but wide gentle beaches, bordered by lagoons and characterised by low energy events. Coastal erosion occurs to varying extent along the entire coastline of Ghana (Alves et al., 2020).

Figure C. 3 l Geology of STMA



The soil type in and around STMA is mainly Acrisols and a "pocket' of Lixisols soil type in the centre of the MMDA (Figure C. 4). Acrisols are often the dominant soil group on old erosional or depositional surfaces and in piedmont areas in humic tropical regions where they are associated and alternating with Nitisols, Ferralsols and Lixisols (Delvaux & Brahy, 2001).

Figure C. 4 l Soil types in STMA



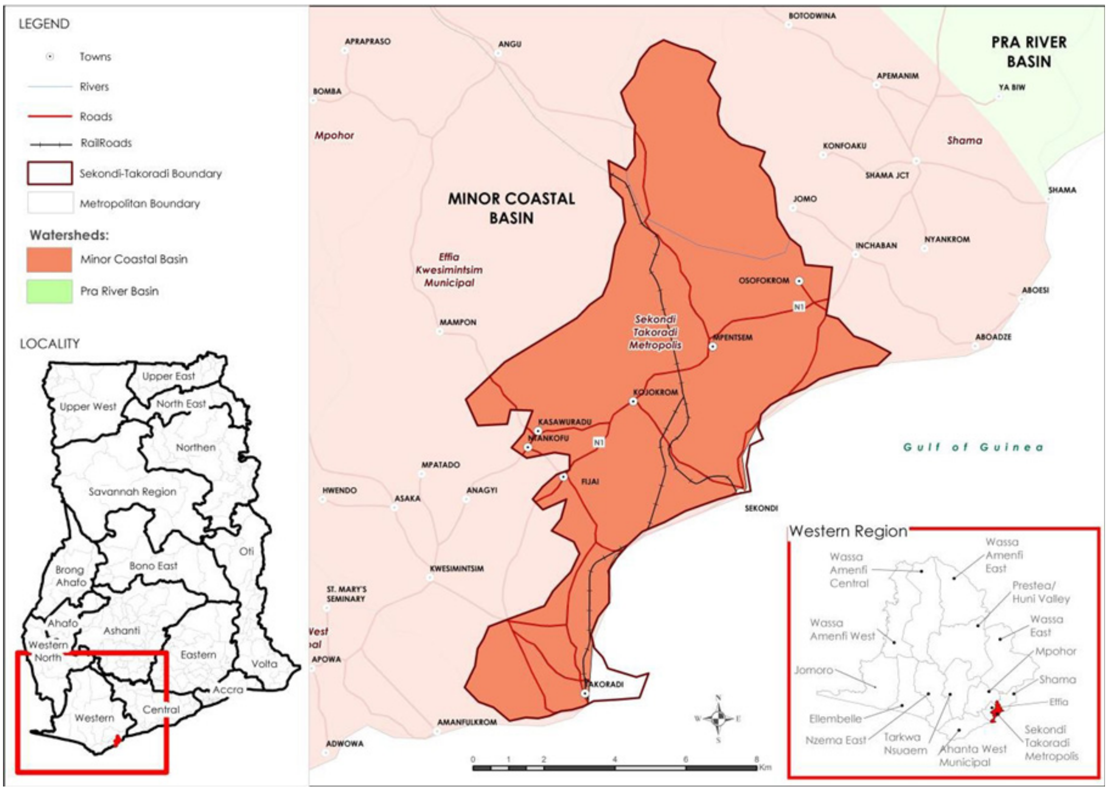
Acrisols form on old landscapes that have an undulating topography and a humid tropical climate. Their natural vegetation is woodland, which in some areas has given way to tree savanna maintained by seasonal burning. The age, mineralogy, and extensive leaching of these soils have led to low levels of plant nutrients, excess aluminium, and high erodibility, all of which make agriculture problematic (Britannica , 2023).

Lixisols develop on old landscapes in a tropical climate with a pronounced dry season. Their age and mineralogy have led to low levels of plant nutrients and a high erodibility, making agriculture possible only with frequent fertilizer applications, minimum tillage, and careful erosion control. Perennial crops are thus more suitable for these soils than root or tuber crops (Britannica, 2023).

Water Resources

Three main river systems drain the country: The Volta river system (which covers 70% of the country area). The southwestern river system comprises the Bia, Tano, Ankobra and Pra rivers (covering 22% of the country area); and the coastal river system (covering the remaining 8% of the country area) comprises the Ochi-Nakwa, Ochi Amissah, Ayensu, Densu and the Tordzie rivers (WWF, 2020). STMA is integrated in the Minor Coastal Basin, in the southwestern river system (Figure C. 5).

Figure C. 5 I Watersheds in STMA



There are six drainage basins in STMA, namely Pokuantra, Kansawura, Buwen, Anankwari, Whin and a minor river basin at Ngyiresia. The two main rivers flowing through the Metropolis are the Whin and the Kansawora rivers, while the lagoons are the Essei and the Butre. (Ministry of Food and Agriculture, website: www.mofa.gov.gh). The Essei lagoon lies between Ekuasi town and the city of Takoradi. The pre-dominate species of fish that populate these rivers and lagoons are tilapia and mud fish. The Atlantic Ocean provides not only sources of food and jobs for the people of the Metropolis but also serves as recreational facility for the people notably during the festive occasion i.e. Christmas and Easter celebrations. This unique natural entity stretches from New Amanful to Essipon (Ghana Statistical Service, 2014).

Mining is predominant in the southwestern river system and in this area pollution of surface water and groundwater has been observed because of the use of cyanide and other poisonous chemicals (WWF, 2020)

Groundwater occurs mainly in the following formations: The Voltaian formation has little or no primary porosity and thus groundwater occurrence is associated with the development of secondary porosity because of jointing, shearing, fracturing, and weathering. In the wet forested southwestern part of the country, the weathered zone has an average thickness of 60m while it is thinnest in the semi-arid area in the extreme northeast where the mean thickness is about 10m. Yields rarely exceed 6 m^3/hr. The Cenozoic and Mesozoic sediments occur mainly in the extreme south-eastern and western part of the country. Three aquifers occur in this formation. The first aquifer is unconfined and occurs in the Recent Sand very close to the coast. It is between two and four metres deep and contains meteoric water. The intermediate aquifer is either semi-confined or confined and occurs mainly in the Red Continental Deposits of sand clay and gravel. The depth of this aquifer varies from 6 m to 120 m. The third aquifer occurs in the limestone and varies in depth between 120 and 300 m. Groundwater in this aquifer occurs under artesian conditions and is fresh. The average yield in this limestone aquifer is about 184 m^3/hr.

Falling groundwater levels have been observed in the Upper Regions where over 2,000 boreholes have been drilled since the mid-1970s in the rural areas to provide potable water to communities (WWF, 2020).

Ecosystems and Biodiversity

STMA has three main vegetation types, namely, mangrove, coastal scrub and savannah woodland. The Mangrove and coastal scrub are found in the southern and middle parts whilst the savannah woodland is found in the northern part respectively.

In Sekondi-Takoradi, there are three major coastal wetlands all of which are confluence of major rivers in the metropolis: Essei and Butuah lagoons at Sekondi and Takoradi respectively, and the Whin estuary at Adakope-Takoradi. The area coverage of the Butuah lagoon in 2010 was estimated at 86.4 km^2 whilst Essei lagoon covered an area of 110.9 km^2. The Whin estuary spanned an area of 652. 2 km^2 (STMA Metro Planning and Coordinating Unit, 2021).

Wetlands in Ghana are very productive, and their resources have been traditionally used by local populations as a source of the basic necessities of life, ranging from building materials and hunting and fishing areas, to sources of water for humans and livestock. Local populations have developed traditional knowledge systems and practices which govern the management of wetlands. Ghana is a signatory to the Ramsar Convention and there are five Ramsar sites of international importance in the country: i) Densu delta; ii) Songor; iii) Keta complex; iv) Muni Pomadze; v) Sakumo lagoons. All these are protected areas and they have been gazetted as such. Other wetlands located in the forest and wildlife reserves of the Mole National Park, and the Black Volta, Sene, Bia and Owabi Wildlife Sanctuaries are protected too. Some wetlands, which fall outside the conserved wetland areas, are subject to traditional conservation practices such as the rivers Ankobra and Pra. (WWF, 2020). Apart from that, the mangroves located around the Essei and Butua lagoons and the Whin Estuary also help in monitoring coastline erosion.

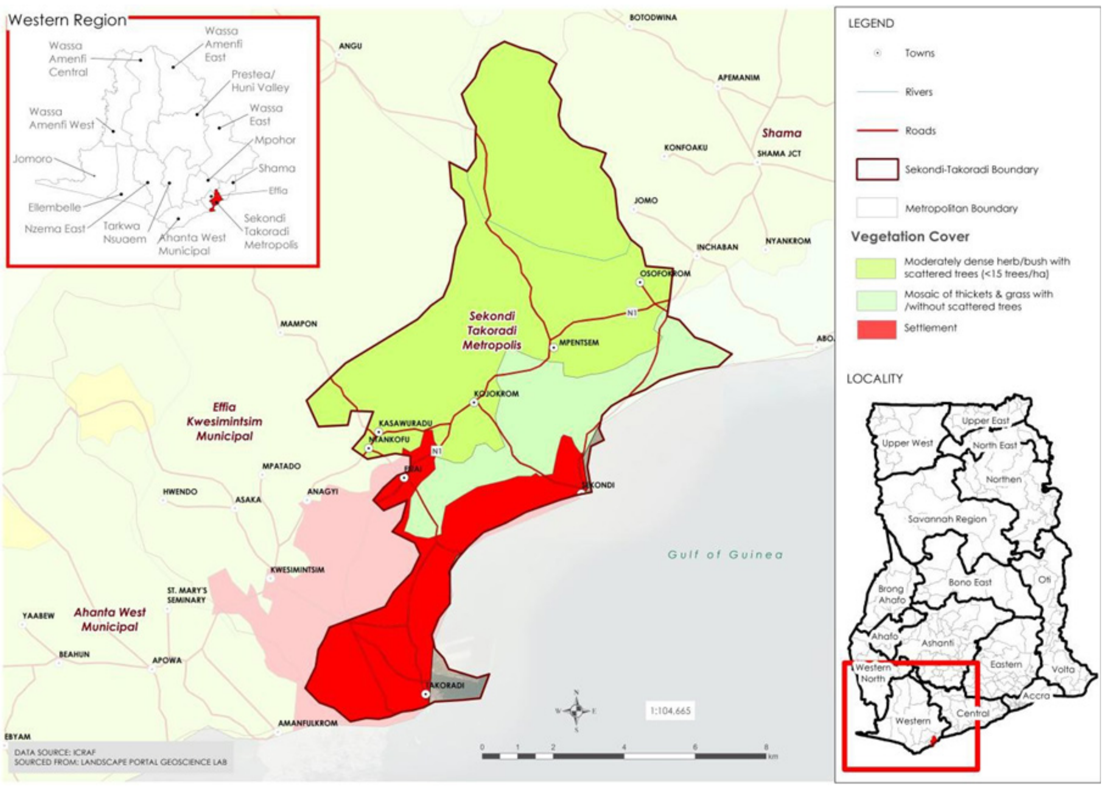
The Butuah Lagoon in New Takoradi serves as a breeding ground for some marine species and is inhabited by a great diversity of species and is also a protected area for fishing with the majority of people in New Takoradi depending on it for their livelihood. A substantial part of Butuah Lagoon is occupied by settlements and industries, which have led to the construction of several drainages, refuse dumps, defecating grounds, animal husbandry, and other intense activities such as fish landing sites around the lagoon. This has resulted in a large tract of wetland near the lagoon, which serves as a buffer zone against flood, which has been heavily polluted (Odjer-Bio, Belford, & Ansong, 2015).

The Essei lagoon located in Sekondi, maintains a permanent opening into the sea as a result of human interference. The wetland areas could be described as low-lying occurring around the lagoon. Fishing in the lagoon is carried out by resident fishermen (Coastal Resource Center-Ghana/Friends of the Nation, 2010).

The Whin River is stretched into two branches forming a Y-shape structure joining and pouring into the estuary. The larger arm lies on the Western side of Adakope, a suburb of Takoradi while the smaller arm is sandwiched between Adakope and Kokompe on the Eastern side of Adakope. The mouth of the estuary lies on the Western side of the African Beach Hotel located on the Habour Road parallel to the shoreline. The bank of the estuary is a mix of beach sand to the Western side and rocky beaches to the Eastern side. Moving away from the mouth of the estuary, the banks are heavily vegetated with tickets of mangrove stands, and the indication of a closed vegetation pattern surrounding the estuary (Coastal Resource Center-Ghana/Friends of the Nation, 2010).

The metropolis is not noted for having a high forest resource since it is an urban setting and most of its land area has been used for other industrial activities. The only forest in the metropolis is the Monkey Hill Conservation Forest which is reserved for eco-tourism. The metropolis will soon lack forest resources considering the deforestation rate and the encroachment of the Monkey Hill Conservation Forest. Therefore, the forest Commission should enforce laws governing forests in the metropolis and sensitize the public on the importance of forests (STMA Metro Planning and Coordinating Unit, 2021).

Figure C. 6 I Vegetation cover in STMA (2015)

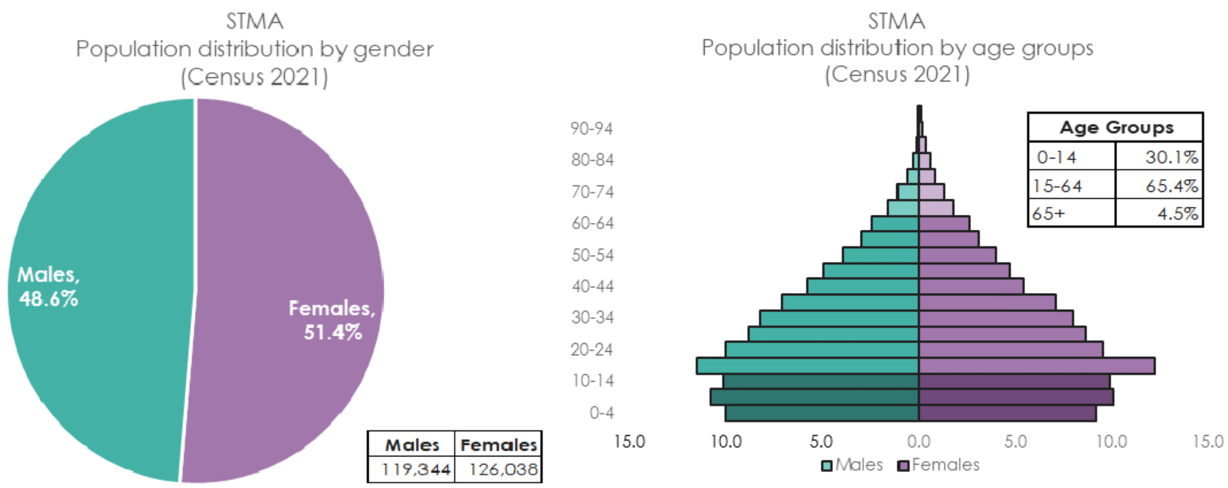


C3 I Demographics

According to the 2021 Ghana Population and Housing Census, the Sekondi-Takoradi Metropolitan Assembly has a total population of around 245 382, comprising 119 344 (48.6%) males and 126 038 (51.4%) females (Figure C-7), and a population density of 3.8 habitants/km². This represents 11.9% and 0.8% of the regional and national population respectively (Ghana Statistical Services, 2021).

The population pyramid included in Figure C. 7 shows the distribution of ages across the STMA population divided down the centre between male and female members of the population clustered by age groups in the horizontal bars. The graphic starts from youngest at the bottom to oldest at the top. The data shows that the Metropolis has a youthful population with the concentration in age group 5-9 and 15-19 years. The age structure of the Metropolis is relatively youthful. The Age-Sex structure of the Metropolis is broad based, comprising of concentration of children at younger ages. The percentage in higher ages reduces gradually in subsequent age groups with a small number of elderly and more females than males at advanced years.

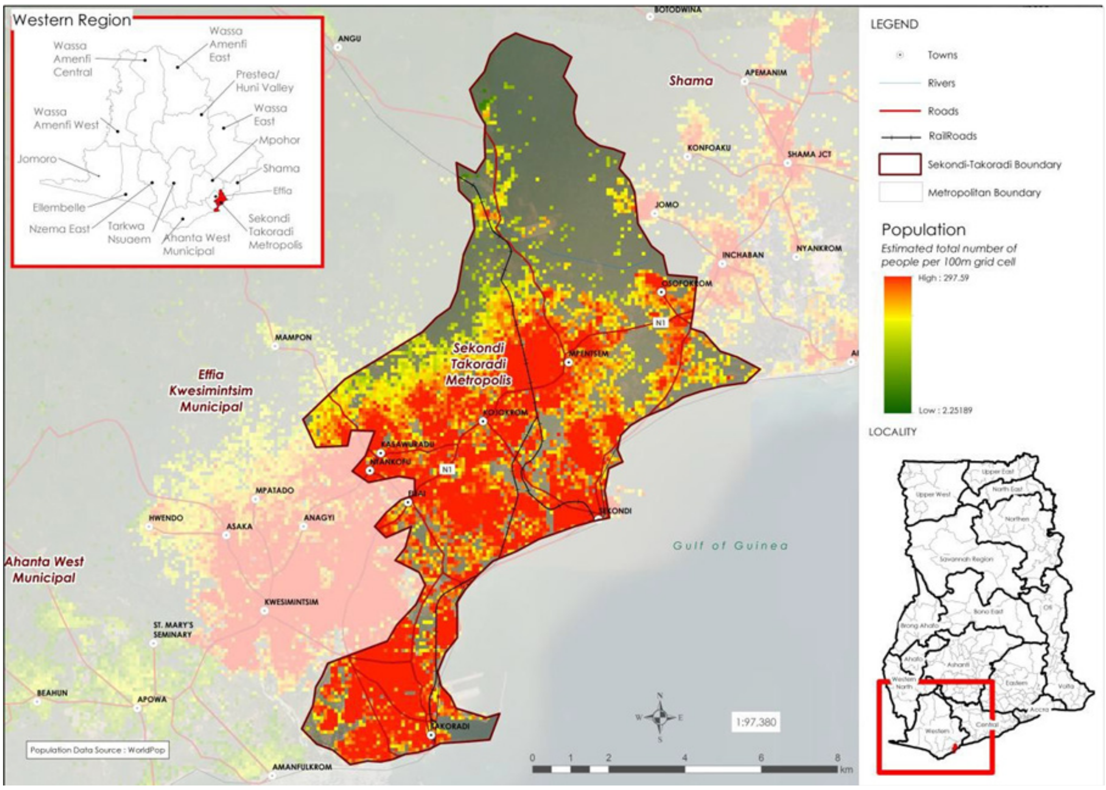
Figure C. 7 I Population distribution by age and gender in STMA



Source: Census 2021

The results from the 2021 Census report specify that the Metropolis is the only district in the Region with 100% urban population, while in the 2010 Census Report, the urban proportion of the total population was 96.1 %, and the rural population was 3.1 % (Ghana Statistical Service, 2014). The latest Census Report (2021) does not categorise the peri-urban areas.

Figure C. 8 | Population distribution in STMA, 2020



Source: Data retrieved from WorldPop (WorldPop Spatial Data Infrastructure, 2022)

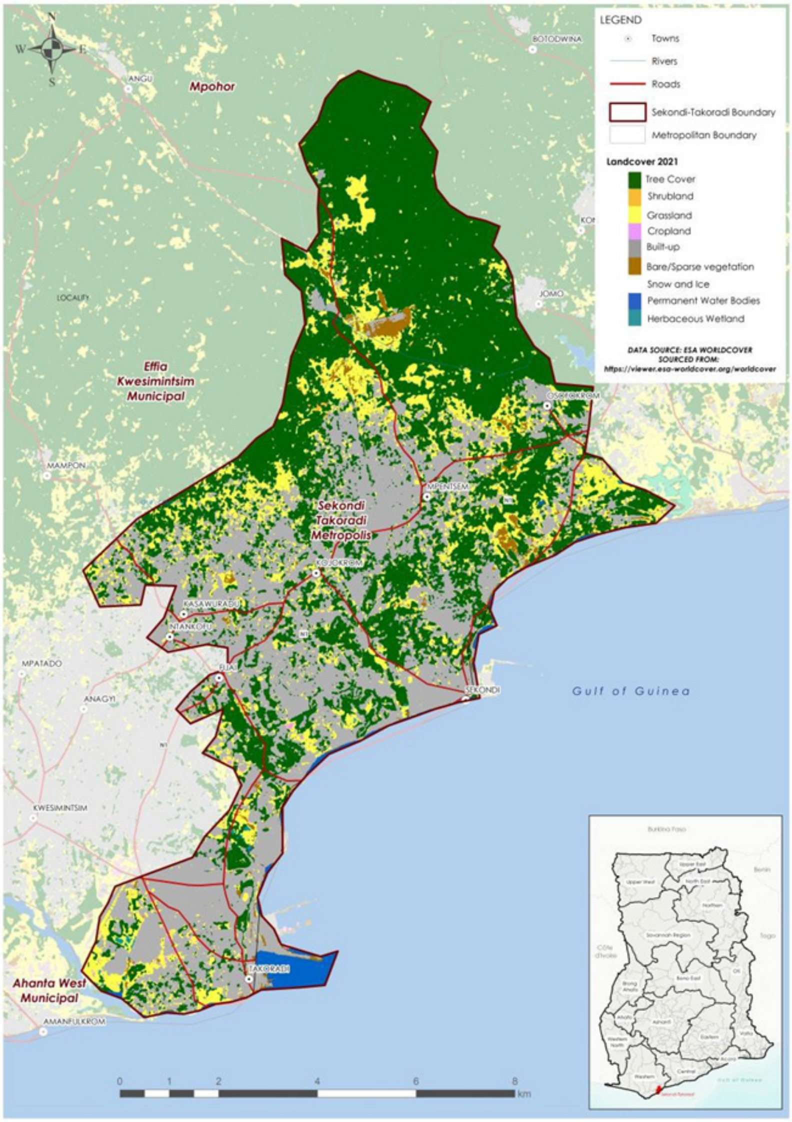
C4 | Land Use and Spatial Planning

Though it is the smallest in terms of land size, STMA is the most urbanized and densely populated local government area in the Region. About 90% of the total land area is the built environment. This comprises residential buildings, offices, industries, markets,

educational facilities, health facilities and many others. Most of the buildings are sky-rise buildings (STMA Metro Planning and Coordinating Unit, 2021). Since oil discovery in Ghana in 2007, Sekondi-Takoradi has gone through a period of rapid of urban change (Eduful & Hooper, 2019). Rapid urbanisation has put a greater burden on the Metropolis in terms of the provision of urban infrastructure and services. The 10% of the land area in the metropolis is used for urban agriculture. This portion is in the northern part of the metropolis. There is a continual high demand for residential housing hence the agricultural land is decreasing as people extend to these areas to build housing facilities. Therefore, the land use pattern of the metropolis can be said to be an urban land use (STMA Metro Planning and Coordinating Unit, 2021). Sekondi-Takoradi Poverty Map, published in 2010, classified the land use patterns into the following categories (CHF International, 2010):

- Predominantly residential;
- Commerce frequently exists within residential areas, creating a “mixed-use” pattern;
- Several central commercial business districts;
- Industry limited to the western and eastern ends; and
- Rapid expansion without any urban sprawl.

Figure C. 9 l Land use in STMA, 2021



C5 l Economy and Employment

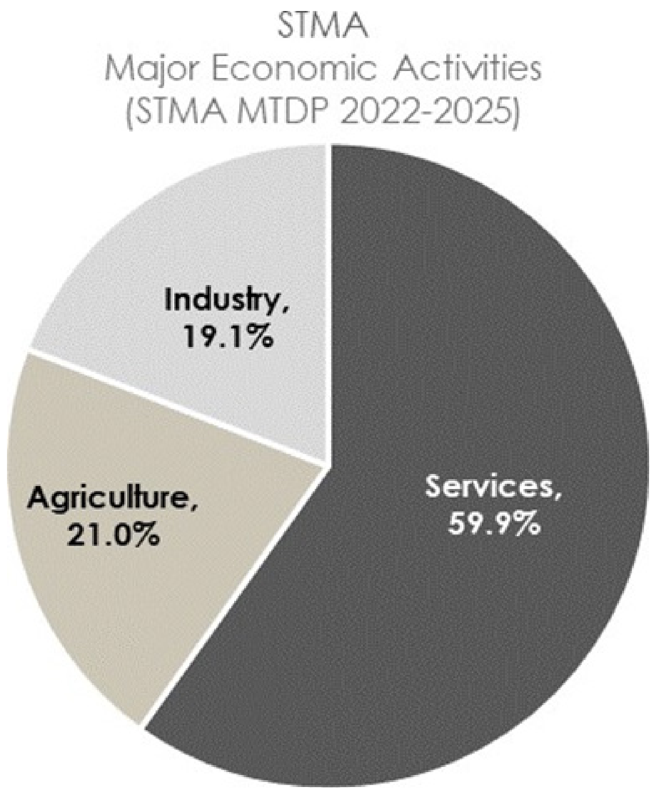
Sekondi-Takoradi is one of the important cities in Ghana in terms of population, economic activities and revenue generation. In recent years and particularly since oil was discovered there in 2007 and production began in December of 2010 the city's prominence has grown both locally and internationally

The economy of the Sekondi-Takoradi Metropolitan Assembly is made up of services (59 %), agriculture (21 %) and industry-related activities (19 %)Figure C. 10). As a result of expansion in communication, energy, transportation, water, and sanitation infrastructure serve as a pull factor to attract migrants into the city in search of better opportunities leading to higher population density. The high population density offers a large market for business activities in the city. This contributes to the attraction of skilled workers, which allows the transfer of knowledge and skills in specialized sectors of the economy such as the oil and gas industry (STMA Metro Planning and Coordinating Unit, 2021).

The private sector is the engine of growth of the economy but an economy with a large proportion of the private sector in informal jobs is an impediment to achieving accelerated economic growth and development.

This is because it is very difficult, if not impossible to tax the self-employed (with or without employees) who are mostly in the informal economy (e.g. market and street vendors). It follows therefore that with such a low tax base, the Metropolis may not receive sufficient revenue from the Internally Generated Fund (IGF). The higher ratio of people in service and sales accounts for the commercial activities in the Metropolis, but this includes mainly retail and wholesale activities which are typically in the informal sector (STMA Metro Planning and Coordinating Unit, 2021)

Figure C. 10 l Major Economic Activities in STMA



Source: (STMA Metro Planning and Coordinating Unit, 2021)

The retail fabric of Sekondi-Takoradi has a high proportion of informal traders. These traders are scattered throughout the city selling a wide range of products and services. They are mostly concentrated along the main roads and receive good support from the residents in the locality. The existing retail facilities can be classified as follows (STMA Metro Planning and Coordinating Unit, 2021):

- Street vendors (hawkers) carry goods in their hands or on their heads.
- Vendors with minor facilities such as tables
- Makeshift structures/sheds often on the side of roads
- Lockable containers or other types of prefabricated structures
- Purpose-built retail buildings can be single or double story built individually, in a linear or clustered in the form of a market.

C6 l Livelihoods and Community

Housing and Living Environment

In 2014, the housing types in the Metropolis could be grouped into the four main categories as shown in Table C. 1.

Table C. 1 l Housing types in STMA (2014)

Housing type	Housing density	Population density	Plot size	Surrounding environment	Services	Neighbourhoods
First Class Areas	Relatively low housing densities	Low population densities (between 30-40 persons per acre)	Large plot sizes (half an acre or more)	Good environmental conditions, etc.	These areas often have good access roads, frequent power supply, potable water and are also serviced by house-to-house Sanitation services	Some of the first class areas are Anaji, Beach Road, Windy Ridge and Chapel Hill. Whereas Namibia, SSNIT flats and the Estates (all within Anaji) are predominantly First Class

Second Class Areas	Housing density is higher than the first class areas	Population density between 80-150 persons per acre	Plot sizes usually between 0.20 to 0.50 acres	Often have fairly clean environmental conditions	Residential areas are places with fairly good roads as well as available utilities (water, electricity, telecommunication, etc.)	Apremdo, Adientem, Mpatado, East and West Tanokrom, Effiakuma, Fijai, Kweikuma, Butumagyebu, Essikado, Sekondi, Bakado, Bakakyir, Takoradi Harbour and Takoradi
Third Class Areas	High housing densities often having more than 6 housing units per acre.	Residential areas have high population (80-150 persons per acre)		Often have poor environmental conditions with choked drains	These areas are also poorly serviced with regard to utilities. These areas are most times inaccessible	Assakae, Kwesimintsim, Effia, Anaji fie, New Takoradi, Ngyinamoa Bakam, Esaman, Ekuase, Nkroful, Nkenya, Ahinkofikrom, Ketan, Mempeasem, Kojokrom, Ngyiresia, Essipong and Mpintsin
Fourth Class Areas	High housing densities	High population densities		These areas are less developed indigenous communities that are poorly served (in terms of basic social amenities). Such settlements basically lack settlement layouts and as such are unplanned. These areas often lack drains and roads rendering these areas mostly un-engineered		Ahanta Abasa, Mampong, Ntankoful, Kansawurado, Whindo, Deabenekrom, Eshiem, Anoe, Osofokrom and Twabewu are often classified as fourth class.

Source: (STMA Metro Planning and Coordinating Unit, 2014)

Food Security

Agriculture continues to play an important role in the economy of the Metropolis, providing both full-time and part-time employment for about 20% of the total population.

It is estimated that about 35% of the land area of the Metropolis is cultivable. The average farm size is about 2 acres. Most of the farmers are into subsistence farming with a few isolated commercial farms. (STMA Metro Planning and Coordinating Unit, 2021).

Major crops grown include cassava, plantain, maize, rice yam, and cocoyam. Vegetables, especial exotic ones, are also extensively cultivated. The most common animals reared in the metropolis include poultry, sheep and goats. Cattle are reared by only a few farmers. The rearing of rabbits, grass cutters and snail production are on the increase. Additionally, there are gari, oil palm, and palm kernel processors in the metropolis. The palm and kernels oils are purchased by soap manufacturers and fish processors in and around the Metropolis (STMA Metro Planning and Coordinating Unit, 2021).

Within the agricultural sector of the economy, fishing is the most common occupation. This includes fishermen, fish sellers as well as fishmongers. However, many people are not able to venture into this occupation especially fishing because they lack the resources to get an outboard motor and hence the metropolis should make available more onboard motors to enable more people to join fishing (STMA Metro Planning and Coordinating Unit, 2021).

The food production sector is beset with a myriad of developmental challenges that require strategic planning and concerted efforts to address them. These challenges include but are not limited to the following (STMA Metro Planning and Coordinating Unit, 2021):

- Poor storage and marketing of the chunk of agricultural produce lead to post-harvest losses.

- Loss of farmlands to human settlement.
- Over-reliance on natural rains for farming activities. This is not sustainable as a result of climate change.
- The use of simple farm tools. Practically, all farm operations are done manually.
- Inadequate field agricultural extension workers.
- Inadequate funding of planned agricultural programmes.
- Lack of logistics for field activities.

Poverty

According to the 2015 Ghana Poverty Mapping Report, Sekondi Takoradi Metropolis was the districts with the highest number of poor persons (68,482) in the region, based on data from the 2010 Population and Housing Census and the 2012/2013 Ghana Living Standards Survey. At the sub-district level, Sekondi has both the highest incidence of poverty (22.9%) and depth of poverty (7.7%). Essikadu-Ketan has the highest number of poor persons (24,593) (Ghana Statistical Service, 2015).

Ghana, like most countries in Sub-Saharan Africa, is undergoing rapid urbanization, with massive growth of its metropolitan areas. The urbanization process and its attendant challenges of increasing poverty and slums development, poor infrastructure, and poor sanitation and waste management, especially in large metropolitan areas such as Accra and Sekondi-Takoradi, are occurring within the context of a decentralization program introduced since 1988 (Owusu & Afutu-Kotey, 2010).

Migration

In Ghana, the growth of industries in the urban centres such as Accra, Kumasi and Sekondi-Takoradi, which created employment opportunities in those areas, have triggered the movement of people to the urban centres. The coastal zone of Ghana is the most industrialised and urbanised area in the country and has been the focus of internal migration since the beginning of the last century. Accra as the nation's capital attracted many administrative and other service workers. With the opening of a deep seaport in Takoradi in 1927, Sekondi-Takoradi became a leading point of attraction for migrants in addition to Accra along the coast (Ghana Statistical Service, 2014). Then, in 2007, the discovery and production of oil attracted not only companies and industries into the metropolis, but also increased the population of migrants who came to look for employment, especially Takoradi where most of the economic activities were found (Fiave R. , 2017).

Overall, migrants to STMA are primarily young people of both genders, from a variety of ethnic groups and socio-economic backgrounds and from all corners of Ghana, but especially from within the Western Region. International migrants are also present, particularly from countries in the West African sub region such as Nigeria, Mali, Burkina Faso, Cote D'Ivoire and Togo. The majority of migrants move into STMA primarily for economic reasons, i.e. to explore income-generating opportunities. Some move for social reasons such as marriage, joining family members who have already migrated, and in order to study in the well-respected secondary and tertiary institutions located in STMA. Given the pressure for residential space within Sekondi-Takoradi, there is an increasing trend for residents to move between areas, especially from the core areas such as New Takoradi and Kwesimintsim, to the peripheral areas such as Assakae. The catalyst for this residential mobility is excess demand over supply of housing, which has made it difficult for many migrant households to find affordable housing (Yankson, Gough, Esson, & Amankwaa, 2017).

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 drives 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).

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, who may lack the resources to rebuild their homes, communities, and livelihoods, and who 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, local of political and wealthy connection, gendered social roles, lack of access to key public services (water, drainage, health facilities, electricity and schooling), location (rural and remote are or excluded neighbourhood within an area) and social norms (Sarwar, Holmes, Korboe, Afram, & Salomon, 2022).

The Department of Social Welfare and Community Development takes the lead role in the Metropolitan Assembly's efforts to promote poverty reduction and ensure income security amongst the vulnerable, marginalized, and disadvantaged groups. Again, the Department works in collaboration with all Social Service agencies, including the Ghana Health Service, Ghana Education Service, DOVVSU, Prison Service, Legal Aid, CHRAJ, NGOs, Media, and the general public. The Metropolitan Assembly has carried out activities like maintenance of children, child custody, paternity, family reconciliation, supervision of daycare centres, registration of NGO's, income generation for rural women, community-based rehabilitation, hospital welfare services, out of school youth programmes, LEAP for the aged, etc. (STMA Metro Planning and Coordinating Unit, 2021)

C7 I Health

There are 64 health facilities made up of 7 Hospitals, 5 Health Centres, 23 Clinics, 2 maternity homes and 27 functional Community-based Health Planning and Services compounds (STMA Metro Planning and Coordinating Unit, 2021).

In 2015, research undertaken by Bonsu to investigate the major death causing diseases in Ghana using Sekondi-Takoradi STMA Catchment Region as a case study, concluded that malaria, skin and ulcers diseases, diarrhoea and other acute respiratory infections were are the major causes of morbidity and mortality, in the region (Bonsu, 2015).

C8 I Infrastructure and Services

Transport

The road network is fairly good with surface dressing and mostly engineered. 50% of the road networks are in good condition and the remaining are either fair or poor. The urban roads network in STMA is 898.5 kilometres. It consists of arterial, distributors/collectors and local roads of which 381.5 kilometres have been paved while the remaining 517 kilometres are unpaved. For most of the day, the arterial road network in Sekondi-Takoradi is congested. This situation, if left unchecked, could choke the Metropolis' transportation network and commercial activities to death and destroy its ecosystem with fuel emissions from vehicles. Key to minimizing congestion and its attendant effects on the economy, health and livelihood of the citizens, is the implementation of an efficient public transportation system along with physical improvement of the arterial road space. The Ghana air force manages internal flights at the Takoradi airstrip. Rail transport lines from Takoradi to Kumasi exits and under rehabilitation. There is severe damage to the road surface due to the heavy traffic load (canalized surface routing) (STMA Metro Planning and Coordinating Unit, 2021).

Invasion of the right of way by informal businesses. Additionally, there are unregulated operations and a lack of strict control for taxis and *trotros* accounting for more than half of the current traffic volume registered in the network (STMA Metro Planning and Coordinating Unit, 2021).

The Metropolis is the main hub of railway network in Ghana. The Railway system has been the main mode of transportation of bulk items like minerals (e.g. bauxite, manganese), cocoa, timber the harbour for export. Not only that but bulk food and other domestic items are also transported from the villages to the urban centres like Accra, Kumasi, and Dunkwa on Offin, Tema, Tarkwa and Takoradi. Aside that it was the main means passenger transport southern half of Ghana until recent times when the rail transport infrastructure began to face serious challenges. The central maintenance workshop of the railways is located in Sekondi where industrial fabrications are undertaken (Ghana Statistical Service, 2014).

The Takoradi Port was built in 1928. It is located in Takoradi. It is well connected to its hinterland which makes it the preferred gateway to the middle and northern part of Ghana as well as the Sahelian countries- Burkina Faso, Niger, and Mali. Annually, the Port handles over 600 vessels, 37% of total national seaborne traffic, 62% of national exports, and 20% of total national imports (STMA Metro Planning and Coordinating Unit, 2021).

The Albert Bosomtwi–Sam Fishing harbor was built in 1999 as a strategic business unit of Ghana Ports and Harbours Authority to be managed as part of Takoradi Port. It is located in Sekondi. It is approximately 25 km West of Takoradi Port and just North of Sekondi Naval Base. The Fishing Harbour comprises the Inner Fishing Harbour, the Canoe Basin, and the Outer Fishing Harbour (STMA Metro Planning and Coordinating Unit, 2021).

There is an Airstrip located in the Metropolis which serves as the base for the Ghana Air Force Flying School and also, as a commercial Airport for domestic flights (Ghana Statistical Service, 2014).

Energy Supply

Households in Sekondi-Takoradi have high levels of access to electricity—97 percent of urban households in the Western Region have access to electricity (Ghana Statistical Service, 2022a) but reliability remains an issue. Relatively frequent outages occur through the region, driven by transmission issues, low water levels in hydropower dams, and gas supply interruptions. In addition to electricity some of the households also use generators to provide electricity during power outages. Others also use rechargeable lamps, solar lamps and candles during periods of power outages (Adusei, 2012).

In STMA households' lighting sources come from six main sources. These include grid electricity, small generators, rechargeable lamps, solar lamps and candles and traditional lamps/paraffin. Energy for cooking also comes from two main sources: gas and charcoal though grid electricity has a limited use (Adusei, 2012).

Ghana's main sources of electrical power are hydro and thermal (mainly fueled 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 continuous decline in the cost of PV and wind technologies and 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).

Part of the thermal energy is generated at the Takoradi Power Station, located approximately 15 km north-east of Takoradi, and consists of three combined-cycle power plants. Being located close to the coastline of the STMA, this power station is potential at risk from increased sea level rise and flooding.

The Volta River Authority, a state-owned energy utility company, which is the main the main generator and supplier of electricity in Ghana, has been developing and implementing policies, programs and introduction of climate smart interventions in the operations of the Authority, to reduce Greenhouse Gas emission levels of the Authority and 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 and 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 leading to significant reduction in carbon emissions (Volta River Authority, 2023).

Water Supply and Sanitation

The Ghana Water Company Limited supplies potable water for domestic, industrial, institutional and commercial purposes within the Metropolis. Also, the Community Water and Sanitation Agency provides boreholes to communities with lower populations within the Metropolis (STMA Metro Planning and Coordinating Unit, 2021). The present water supply to the Sekondi Takoradi Metropolitan Assembly (STMA) is from two headworks at Daboasi and Inchaban, wich also supply water to the nearby towns in the Shama and Ahanta West Districts. The Daboase Headworks abstracts water from the Pra River and the Inchaban Headworks treats raw water taken from a dam on the Anankwar River. The Inchaban facility was constructed in 1928 with an installed capacity of 15 000 m^3/ day. However, the average water supply from this facility has been reducing and in 2013 was at half of the installed capacity. During most periods in the year, this reduces even more to approximately 3 785 m^3/day. The Daboase facility on the other hand, was constructed in 1969 with an installed capacity of 22 700 m^3/day but in 2013 was producing about 16 000 m^3/day on average. Available statistics indicate that water demand in the STMA and its nearby towns in 2013 was 25 000 m^3/day. This was projected over 37 850 m^3/day in 2025, assuming that there will be a population increase in STMA (Coastal Resources Center, 2013).

In the coastal districts of the Western Region, water supply systems for domestic consumption are increasingly stressed by a rapidly growing population, the construction and operation of large new industrial facilities spurred by the production of oil and gas and the associated hospitality and tourism industry. As demand for water increases, poor households face challenges in accessing water for their domestic needs. As the overarching planning authorities in their areas of jurisdiction, district assemblies and municipal authorities need to increase their investments in groundwater abstraction and thereby increase access to potable water in water-stressed communities (Coastal Resources Center, 2013).

There are about 9 main sources of water for households within the Metropolis. Out of this total, six (6) are potable sources whiles the remaining three (3) are considered not potable sources. The potable sources include: In-house tap, in-yard tap, in the yard well (covered), public well (covered), borehole and public taps whereas the non-potable sources include in the yard well (not covered), surface water, and public well (not covered) (STMA Metro Planning and Coordinating Unit, 2021). While the STMA and major towns in Shama and Ahanta West districts obtain piped-water supply from the Daboase and Inchaban facilities, communities in the Jomoro, Ellembelle and Nzema East districts are mostly served by boreholes and hand-dug wells and through the small-town water supply systems. Consequently, most communities in these areas lack access to piped water at the household level. It is therefore common to see lines of women and children carrying water from a borehole or stream distant from their dwelling in these areas (Coastal Resources Center, 2013).

About 78% of households in Sekondi-Takoradi have undesirable access to toilet facilities. Among households in the Metropolis, only 17% have access to household water closet toilet facilities, while 49% use public toilet facilities. Desirable toilet facilities are water closets or Kumasi Ventilated Improved Pit latrines, located within the housing unit. Undesirable toilet facilities include a bucket/pan, a facility in another house, or a public toilet. About 78% of households residing in informal settlements within the Sekondi-Takoradi Metropolis have undesirable access to toilet facilities. There are 102 public toilets meant to serve commuters scattered in the Metropolis, but they have been turned into community toilets as many residents (over 80%) lack household toilet facilities, rely heavily on these public toilets. This has resulted in high incidences of open defecation in communities like New Takoradi, Nkotompo, Ngyiresia and Kojokrom (STMA Metro Planning and Coordinating Unit, 2021).

Stormwater and Flood Risk Management

The central area of STMA has an altitude of only 6 m above sea level which is low lying.

The general low-lying nature of the topography especially in the coastal areas is a key challenge as heavy rains results in frequent flooding and increase the pressure on stormwater drainage and critical infrastructure (STMA Metro Planning and Coordinating Unit, 2021).

It has been observed that the severity of the floods increases with each passing year. To alleviate the drainage and flooding problems in the existing basins, STMA and other relevant authorities have acknowledged that there is a strong need for an integrated approach with neighbouring Municipalities. There is the need to revisit or review the Drainage Master Plan Report of 2006. The implementation of the revised plan will serve as a basis for the development, control and implementation of future drainage improvement works (STMA Metro Planning and Coordinating Unit, 2021).

Waste Management

Sanitation and Waste Management is the sole responsibility of the Metropolitan Assembly. Presently four (4) waste management services are engaged to perform this major responsibility through the adoption of the polluter-pay principle. The solid waste generated amounts to 614 tons/day with collection at 360 tons/day. This results in 224,724 tons/year generation and 131,760tons/year collection respectively. The final disposal system is controlled tipping at the engineered landfill site for solid waste and an oxidation system for liquid waste disposal. The waste collection system being operated in the metropolis is a mix of door refuse collection systems and communal container lifting systems. Newly developed areas in the Metropolis are poorly served with services such as water, electricity, telecommunication and other ancillary services (STMA Metro Planning and Coordinating Unit, 2021).

C9 I Future Growth and Development Planning

Expansion of production infrastructure to boost agriculture, industrial production, and the service sector especially the tourism industry remains the outermost priority of the Metro as stipulated in its MTDP. The Metro has therefore outlined plans, programmes, and projects within key thematic areas of the National Medium Term Development Planning Framework (NMTDPF) to embark on between the

periods2022 to 2025. These actions are informed by a situational analysis that identified developmental challenges as well as their implications on sustainable development, gender equity and the most significant multiplier-effect on the large proportion of the populace.

The priority actions include increasing revenue mobilization through improvement in revenue administration, effective property rate collection, and expanding the tax net and providing reliable and accessible infrastructure and services by investing in infrastructure development, strengthening public-private partnerships, improving waste management, increasing access to water and sanitation, and taking proactive actions to protect the environment and potential climate change impacts.

The strategy to attain a sustainable economic growth and development includes promotion of tourism and investment, improvement of agricultural production and marketing, and the development of the informal sector. The district further seeks to reduce inequality and promote local governance and participatory decision-making by enhancing the capacities of local institutions, improving transparency and accountability, and promoting civic engagement and participation.

In addition, the Metro also seeks to develop its human resources and institutional capacity through capacity building and training for staff, improving coordination and communication, and strengthening monitoring and evaluation systems.

Appendix D 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. 1I 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 assets.

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, socio-economic 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