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Climate Change Risk and Vulnerability Assessments and Adaptation Action Plan for the Water Sector in Ghana

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

FREEDOM AND JUSTICE

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This symbol in the NAP Logo represents Ghana's Climate Change Risk and Vulnerability Assessment and Adaptation Plan for the water sector.

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Abbreviations and Acronyms

CCRA	Climate Change Risk Assessment
CSIR	Council for Scientific and Industrial Research
CWSA	Community Water and Sanitation Agency
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FDA	Food and Drugs Authority
FRM	Flood Risk Management
GCF	Green Climate Fund
GDP	Gross Domestic Product
GIDA	Ghana Irrigation Development Authority
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
GMet	Ghana Meteorological Agency
GSS	Ghana Statistical Service
GWCL	Ghana Water Company Limited
HSD	Hydrological Services Department
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LC	Lands Commission
LRS	Length of Rainfall Season
MCDM	Multi-Criteria Decision Making
MLGRD	Ministry of Local Government and Rural Development
MLNR	Ministry of Lands and Natural Resources
MoF	Ministry of Finance
MoFA	Ministry of Food and Agriculture
MoFAD	Ministry of Fisheries and Aquaculture Development
MoGCSP	Ministry of Gender, Children and Social Protection
MWRWH	Ministry of Water Resources, Works and Housing

NAP	National Adaptation Plan
NGOs	Non-Governmental Organizations
PPPs	Public-Private Partnerships
PURC	Public Utilities Regulatory Commission
SDGs	Sustainable Development Goals
SMEs	Small and Medium Enterprises
TDS	Total Dissolved Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations Office for Disaster Risk Reduction
VBA	Volta Basin Authority
VLTC	Volta Lake Transport Company
WRC	Water Resources Commission
WRIS	Water Resources Information Services

Executive Summary

Background - Climate change poses significant challenges to Ghana's water resources, with shifting rainfall patterns, prolonged droughts, and rising temperatures placing immense pressure on water availability and quality. These changes are already disrupting essential services, including household water supply, agriculture, energy production, and ecosystems. As water is a vital resource supporting multiple sectors of the economy, any disruption could have far-reaching social and economic consequences.

The impacts of water scarcity and flooding are most severe in communities that depend on natural water sources for their livelihoods, particularly rural and low-income populations. Women and girls are often disproportionately affected, as they bear the primary responsibility for water collection and domestic use, making them more vulnerable to water shortages and contamination-related diseases. The situation is further compounded by existing gender and socioeconomic inequalities, which limit access to water resources and adaptation opportunities.

To effectively tackle these challenges, adaptation strategies must integrate inclusive, community-centred, and gender-responsive approaches. Promoting equitable access to water and enhancing resilience within the water sector will be critical to safeguarding livelihoods, supporting sustainable development, and ensuring that no one is left behind in the face of climate change.

Aim and Approach - The National Adaptation Plan for the water sector aims to reduce the sector's vulnerability to climate change impacts by enhancing adaptive capacity and resilience. The plan seeks to mainstream climate change adaptation into existing and future policies, regulations, and development initiatives related to water management. It promotes sustainable water resource management practices that ensure reliable water supply, protect ecosystems, and support climate-resilient livelihoods.

The plan emphasizes building institutional and community capacity by enhancing knowledge, promoting sustainable technologies, and supporting inclusive water governance. Key stakeholders, including water management authorities, local communities, and private sector actors, are engaged to drive adaptation actions and ensure long-term impact.

The approach adopted a top-down methodology, which included a comprehensive desk review, climate analysis, risk analysis, iterative revisions and final validation. The final plan reflects expert inputs for engagement with policy makers and community leaders for inclusivity aligned with national development goals.

Key Findings - The National Adaptation Plan for the water sector identifies critical climate change risks, including erratic rainfall patterns, prolonged droughts, floods, and declining water quality and availability. These challenges threaten water security, disrupt livelihoods, and hinder progress toward Sustainable Development Goal Six (clean water and sanitation). The action plan proposes a comprehensive set of nature-based, technological, and policy-driven adaptation measures to enhance the resilience of water resources and reduce climate-related vulnerabilities.

Key adaptation actions include promoting sustainable watershed management through afforestation, wetland protection, and soil conservation practices. Additionally, the plan recommends developing and modernizing water storage infrastructure, such as reservoirs and rainwater harvesting systems, to buffer against droughts and erratic rainfall. Strengthening groundwater monitoring systems and regulating borehole drilling practices are also proposed to ensure sustainable groundwater use.

To improve water supply resilience, the plan promotes diversifying water sources and expanding community-based water supply schemes, particularly in water-scarce regions. It emphasizes using digital tools, such as smart metering and remote sensing, to monitor water usage and reduce losses. Additionally, the plan calls for strengthening water treatment systems to safeguard water quality during flood events and increasing public awareness on water conservation practices. The plan proposes developing early warning systems for floods and droughts and building climate-resilient water infrastructure, including flood control dams and drainage systems. Community-based approaches, such as constructing buffer zones along water bodies and restoring riparian vegetation, are recommended to reduceflood risks and protect water resources.

The action plan emphasizes a coordinated, multi-stakeholder approach to implementation. It highlights the roles of key institutions, including the Ministry of Sanitation and Water Resources, Water Resources Commission, Ghana Water Company Limited, Community Water Sanitation Agency, and the National Disaster Management Organization (NADMO). The report recognizes that Ghana has a robust legal and policy framework addressing water resource management and climate adaptation, including the National Water Policy, National Climate Change Adaptation Strategy, National Adaptation Plan Framework, and the Nationally Determined Contributions.The proposed adaptation measures aim to ensure equitable and sustainable water access, protect ecosystems, and enhance community resilience to climate change impacts on water resources.

Implementation Challenges - The implementation of the water sector adaptation plan faces several key challenges, including financial and logistical constraints, capacity gaps, inconsistent government commitment, and weak institutional coordination. Heavy reliance on external funding often causes project delays, highlighting the need for dedicated budget allocations and innovative domestic financing mechanisms such as resource usage fees, environmental taxes, and public-private partnerships (PPPs). Capacity gaps, particularly at regional and district levels, require targeted training, mentorship programs, and knowledge-sharing initiatives to strengthen technical expertise. Inconsistent government commitment, policy gaps, and shifting priorities undermine progress, necessitating continuous political will, accountability mechanisms, and stakeholder engagement. Additionally, fragmented roles and poor coordination among institutions hinder effective implementation, making it crucial to establish clear mandates, improve communication, and harmonize policies for streamlined execution.

Recommendations - The report emphasizes the need to increase funding and investment for the water sector through nnovative financing mechanisms and public-private partnerships. Implementing Integrated Water Resources Management (IWRM) and promoting sustainable land management practices are critical for ensuring long-term water security. Adopting nature-based solutions, efficient water uses practices, water recycling, and advanced irrigation techniques will enhance resilience to climate change impacts. Additionally, strengthening water management infrastructure, expanding water storage and conservation techniques, and promoting ecosystem restoration of freshwater resources are key adaptation measures. Sustainable groundwater extraction, minimizing water losses, and exploring desalination projects are recommended to improve water availability. The report also highlights the importance of community engagement, education, and establishing robust monitoring and evaluation frameworks to track progress. Furthermore, integrating gender-sensitive approaches and empowering marginalized groups will promote inclusivity in adaptation efforts. Lastly, strengthening institutional frameworks, clarifying roles, and enhancing governance structures will be essential for effective implementation and coordination.

1. Context and Rationale

1.1. Background

Changes in the earth's climate system caused by anthropogenic activities have become a major concern in recent times (Allen et al. 2018). Significant consequences of this are the expected changes in the trends of climatic variables, especially rainfall which in turn have a great impact on the human systems (IPCC 2014). The impact of rainfall on society compared to other climatic variables is phenomenal, and so an examination of its behaviour under current and future climate change scenarios is needed. Various studies have evaluated long-term potential changes in rainfall, including for Africa (Giorgi et al. 2009; Hewitson et al. 2012; Endris et al. 2013; Dosio and Panitz 2016; Kisembe et al. 2018; Okafor et al. 2019). For example, remarkable increases in heavy rainfall events and dry extremes are expected in places already experiencing annual rainfall increases and average rainfall decrease, respectively (Shongwe et al. 2009).

Sustainability of water resources has become a global debate in this era of climate change. Globally, accessible freshwater resources are less than 1% of the global water stock and its uneven spatial and temporal distribution, along with overexploitation of water resources for human activities, which often causes water scarcity (Savenije, 2000; Hoekstra and Mekonnen, 2011). Anthropogenic degradation of watersheds is one of the main direct causes of freshwater scarcity (Murphy and Kapelle, 2014). Water sustainability depends on ecosystem structure and function in a watershed, and a current challenge due to unplanned use resulting from population and economic growth, changes in land use and global dynamics. It is further threatened by climate change at the global, regional and local scale (Enanga et al., 2011; Boon and Ahenkan, 2012; Bangash et al., 2013; Niang et al., 2014; IPCC, 2014; World Bank Group, 2016).

A potential constraint to food production is the threat of water scarcity (Steduto et al., 2012; Davis et al., 2015). The Intergovernmental Panel on Climate Change (IPCC, 2007) projected 10 – 30% reduction in water availability by 2050 over some dry regions at mid-latitudes and in the dry tropics. This is particularly concerning as some of these locations are currently water-stressed. Floods and droughts are the notable extreme impacts of climate change, evidenced mostly in Sub-Saharan Africa, causing significant economic losses due to the low resilience capacity of the region resulting from high poverty and political instability (UNEP, 2002; Boet al., 2004; FAO, 2009; Davis et al., 2015).

In Ghana, seasonal rainfall amount is expected to increase in all the agro-ecological zones in Ghana by the end of the twenty-first century at a rate of 10–40%. Rainfall projected under RCP 4.5 showed an increasing trend of rainfall in the early (2011–2040) and late (2070–2100) period of the century and was on the average 2% higher than RCP 8.5 in all the seasons throughout the century (Bessah et al., 2021). Research conducted by the Water Footprint Network (2018) showed that Ghana annually faces blue water (amount of surface or ground water used for the production of a good or service) scarcity during the dry seasons (November – February). Studies show that climate change is expected to further worsen this situation as it may result in erratic rainfall in the tropics which would alter the trend of runoff and river flows (Milly et al., 2005; IPCC, 2007; López-Moreno et al., 2011). The trend of change in water availability is inconsistent in Ghana under different climate models (Kasei, 2009; Obuobie et al., 2012; Nutsukpo et al., 2013; Amisigo et al., 2015). Climate change adaptation in the water sector would enhance resilience and stabilize food production, thereby addressing key SDGs like #1 zero hunger, #2 no poverty, #6 clean and safe water, and #13 climate action.

Socioeconomic groups, including women, men, children, the elderly, and individuals with disabilities, face varying levels of vulnerability to climate change impacts. Among these groups, women often experience heightened vulnerability due to their daily activities that involve the use of water. In a typical Ghanaian setting, women and children are responsible for cooking, washing, and almost all house chores. This resource will be adversely impacted by climate change (IPCC, 2022). Incorporating a gender perspective in the adaptation plan allows for a nuanced understanding of how climate change impacts are experienced differently, not only between men and women but also within these groups, considering factors such as age, education, ethnicity, and marital status. A gender-responsive approach aims to address these disparities, ensuring that adaptation strategies do not perpetuate or exacerbate existing gender inequalities but promote equity and inclusiveness (FAO and UNDP, 2018).

This plan provides a framework for addressing climate change adaptation in the water sector. As part of Ghana's broader National Adaptation Plan (NAP) process, it aims to integrate water-related climate change considerations into national decision-making and planning. The NAP process, established under the Cancún Adaptation Framework in 2010 and adopted by UNFCCC parties in 2011, focuses on enhancing adaptive capacity and resilience while reducing vulnerability to climate change impacts. For the water sector, this involves strategic planning to address medium- and long-term adaptation needs, including ensuring sustainable water resource management, equitable access, and resilience against water-related risks such as droughts, floods, and water scarcity.

The NAP for Water emphasises the importance of safeguarding water resources critical to human well-being, economic activities, and ecosystem health. By promoting sustainable water management practices, the plan aims to enhance the resilience of water systems to climate variability while protecting communities and livelihoods dependent on these resources. Recognizing the cross-cutting nature of water, the plan integrates sectoral coordination to ensure that water security is maintained and enhanced across various sectors, including agriculture, health, and urban development.

1.2. Aim and Objectives

The NAP for the Water Sector of Ghana aims to address the impacts of climate change on water, which is a critical sector for the country's economy. The plan seeks to reduce the sector's vulnerability to the adverse impacts of climate change by building adaptive capacity and resilience. It aims to facilitate the integration of climate change adaptation into existing and future fiscal, regulatory, and development policies, programmes, and activities. The plan supports integrated water management by promoting practices that enhance the sustainable use of water and the conservation of its resources. It focuses on strengthening the capacity of water users, water-related institutions, and other stakeholders to adapt to climate change through training, education, and access to climate-resilient technologies. It also encourages research and innovation to develop new knowledge, techniques, and technologies that are resilient to climate change. The plan aims to mobilize resources from national and international sources to support adaptation initiatives in the water sector. However, the overarching aim of this assignment is to develop a costed sector adaptation plan and to build the agricultural sector's capacity to mainstream adaptation considerations in Ghana's agricultural and climate change policies and plans.

The following specific objectives guide the assessment:

- To conduct rapid climate risk assessments in the water sector.
- To develop a costed adaptation plan for the water sector.

1.3. Gender-Responsive Action Plan for the Water Sector

Climate change is anticipated to deepen the existing poverty and intensify inequalities due to gender differences in sociocultural and economic roles and responsibilities. In the water sector, significant gender-based disparities exist in areas like who is responsible for ensuring the availability of water for house chores, time spent on water collection, and participation in decision-making related to water management. For instance, women and girls in many communities bear the primary responsibility for fetching water, often travelling long distances, which increases their vulnerability to climate-induced water scarcity and places additional constraints on their time and opportunities for education and economic activities. Similarly, unequal participation in water governance limits the ability of women to influence decisions that affect their lives and communities (Siedu et al., 2021).

Adopting a gender-sensitive approach in the water sector ensures that the voices and perspectives of women are considered in formulating and implementing adaptation strategies, leading to more inclusive and effective solutions. By integrating gender perspectives, Ghana can gain a deeper understanding of community vulnerabilities and capacities, particularly regarding water access and management, resulting in more equitable and sustainable adaptation outcomes (Wrigley-Asante & Dake, 2019).

A gender-responsive approach to water-related adaptation strengthens resilience by leveraging the different capacities, experiences, and perspectives of men and women in managing water resources and addressing climate risks. Such an approach recognizes gender differences in adaptation needs and opportunities while ensuring equitable participation and influence of both men and women in water governance and decision-making processes. Additionally, it ensures gender-equitable access to financial resources, infrastructure, and benefits arising from investments in climate-resilient water management systems (FAO and UNDP, 2018). By addressing these disparities, Ghana's adaptation plan can promote gender equality and climate resilience in the water sector.

1.4. Purpose of the Water Sector Adaptation Pan

The purpose of the Sectoral Adaptation Plan for Water is to provide a strategic framework that guides Ghana's water resources in adapting to the impacts of climate change. This plan aims to ensure the sustainability and resilience of water practices, thereby securing food security, improving livelihoods, and supporting economic development. The Action Plan seeks to facilitate the integration of gender considerations into policies, programs, and strategies related to agricultural development about climate change. The key objectives include:

- **Enhance Water Security:** Ensuring a consistent and sustainable water supply is central to this plan. Key strategies include adopting innovative water management practices, expanding rainwater harvesting initiatives, and investing in climate-resilient water storage and distribution infrastructure. These measures aim to reduce the vulnerability of communities and industries to the effects of drought and irregular rainfall patterns.

- **Improve Livelihoods:** Reliable water resources are vital for communities relying on agriculture, aquaculture, and other water-dependent livelihoods. This plan focuses on improving access to safe and clean water while equipping individuals and businesses with tools and training for efficient water use. Promoting water-saving technologies and practices will enhance productivity, secure incomes, and bolster community resilience.

- **Support Economic Development:** Water is critical in driving economic activities such as farming, energy production, and industrial operations. By addressing climate-induced water challenges, the plan ensures stability in water-dependent sectors, fostering sustained economic growth and safeguarding key industries from disruptions caused by water shortages or flooding.

- **Promote Sustainable Water Practices:** Long-term conservation of freshwater resources and aquatic ecosystems is integral to the plan. This includes implementing watershed protection measures, advancing groundwater recharge techniques, reducing pollution, and empowering communities to lead water conservation efforts. These initiatives aim to secure water resources while maintaining environmental integrity and biodiversity.

The strategic actions for the adaptation plan also include:

- **Risk Assessment and Management:** Conducting comprehensive assessments of climate risks and vulnerabilities specific to water resources. This includes identifying regions and communities most at risk of water scarcity, flooding, and water quality degradation to prioritise interventions and develop targeted adaptation strategies.

- **Capacity Building:** Strengthening the capacity of water resource managers, local authorities, and communities through training and education on climate-resilient water management practices and technologies, including efficient irrigation methods, flood control systems, and sustainable water harvesting techniques.

- **Research and Innovation:** Investing in research to develop innovative solutions for climate adaptation in water management. This includes developing improved water conservation technologies, advanced water treatment systems, and climate-resilient infrastructure to optimise water use and ensure supply during extreme weather events.

- **Policy Integration:** Ensuring climate adaptation strategies are integrated into national and local water management policies and planning frameworks. This promotes a coordinated, multi-sectoral approach to managing water resources in a changing climate.

- **Monitoring and Evaluation:** Establishing robust systems for monitoring and evaluating the impacts of climate change on water resources and the effectiveness of adaptation actions. This enables continuous improvement and informed decision-making to enhance water resilience.

- The Sectoral Adaptation Plan for Water is vital to Ghana's comprehensive climate strategy. By focusing on enhancing water security, improving livelihoods, supporting economic development, and promoting sustainable water practices, the plan aims to build a resilient water sector. Coordinated efforts, research-driven innovation, and inclusive policy frameworks will ensure that Ghana's water resources remain sustainable and accessible for all, even amid climate-related challenges.

1.5. Definitions

1.5.1. Gender

Gender refers to the socially constructed roles, behaviours, and expectations placed on individuals based on their perceived sex, influencing their access to, control over, and management of water resources. These roles are shaped by cultural, economic, and political factors and often result in gender-specific vulnerabilities and opportunities when it comes to water access and climate change impacts. In the water sector, gender-sensitive approaches focus on recognizing and addressing the different ways in which men, women, and other gender identities experience and respond to water-related challenges, including scarcity, pollution, and climate variability.

By incorporating gender considerations into water management and climate change adaptation, we can ensure more inclusive, equitable, and practical strategies that address the specific needs of all individuals. Gender-responsive adaptation not only aims to reduce the vulnerabilities of women and marginalized groups, who often bear a disproportionate share of the water-related impacts but also seeks to empower these groups by promoting their active participation in water governance and decision-making. This approach ultimately fosters more resilient and sustainable water management systems that are responsive to the diverse needs of all people.

1.5.2. Gender Responsiveness

In the water sector, Gender Responsiveness refers to the deliberate and proactive incorporation of gender perspectives into the development, execution, and management of water-related policies, initiatives, and projects. It recognizes that men, women, and other gender groups experience and interact with water resources in distinct ways due to socially constructed roles, responsibilities, and access to power. A gender-responsive approach ensures that these differences are acknowledged and addressed, leading to more equitable access, participation, and benefits for all.

This approach emphasizes the importance of including women and marginalized groups in decision-making processes related to water governance, ensuring their voices are heard and their contributions valued. It also promotes equal opportunities for leadership and decision-making roles in water management, fostering inclusive and collaborative approaches. Given the gendered dimensions of water access whether for domestic use, agriculture, or sanitation, gender responsiveness tailors solutions to different groups' specific needs and challenges, thereby enhancing the effectiveness and sustainability of water resource management.

Ultimately, gender responsiveness in the water sector aims to reduce inequalities, empower all genders, and create more resilient, equitable, and sustainable water systems. It acknowledges the diverse experiences, responsibilities, and contributions of different gender groups, ensuring that water management is inclusive and benefits everyone equally.

1.5.3. Climate Change

Climate change refers to long-term alterations in temperature, precipitation patterns, and other climate conditions resulting from both natural processes and human activities. It is primarily driven by human-induced factors, including the emission of greenhouse gases, deforestation, and industrial activities, which significantly alter the atmosphere's composition and disrupt the natural climate system. Over time, these changes lead to shifts in climate patterns, affecting water resources, ecosystems, and communities globally.

In the context of water resources, climate change has profound impacts, including changes in water availability, quality, and distribution. Rising temperatures and altered precipitation patterns can lead to more frequent and intense droughts, floods, and storms, further exacerbating water scarcity and contamination. These changes pose risks to water security and have direct consequences on agriculture, sanitation, and human health. The persistent nature of these climate shifts requires adaptation strategies that ensure sustainable water management and resilient communities.

1.5.4. Climate Change Adaptation

Climate change adaptation refers to adjusting human and natural systems to respond to climate change's direct and indirect impacts. In the context of the water sector, adaptation involves implementing strategies and practices that help communities and ecosystems cope with changing water availability, quality, and distribution due to climate variability. This includes modifying infrastructure, water management systems, and policies to reduce vulnerability and enhance resilience to climate-induced stresses such as droughts, floods, and altered rainfall patterns.

Adaptation strategies may involve improving water conservation, enhancing flood protection measures, and restoring water ecosystems to increase their capacity to cope with changing conditions. Additionally, it focuses on capacity-building and fostering innovation to ensure communities, especially those dependent on water resources, can thrive in a changing climate. By addressing current and future climate risks, adaptation efforts help minimise damage while seizing opportunities that arise from climate change, ensuring sustainable and equitable water resources for present and future generations.

1.6. Structure of the Water Sectoral Plan

The first chapter provides the plan's background, outlining its aims and objectives. It explains the purpose of the sectoral plan and describes its structure, setting the stage for the detailed discussions in the subsequent chapters. The approach and methodology used in developing the sectoral adaptation plan are presented in chapter two. It includes the processes, tools, and frameworks employed to gather data, engage stakeholders, and formulate the plan. Chapter three provides the situational analyses of the water sector in Ghana, focusing on the three key sub-sectors river systems, groundwater, reservoirs, and wetlands.

Chapter four examines the trends in climate change at the national level. It discusses historical climate data, current trends, and future projections, highlighting the implications for the water sector. Chapter five focuses on the impacts of climate change on the water sector and analyses the sector's vulnerabilities. It identifies the key risks and challenges climate change poses to water resources in Ghana.

Chapter six outlines the proposed actions to address climate change risks in the water sector in Ghana. These actions are designed to address the vulnerabilities and enhance Ghana's water systems' resilience. In chapter seven, the report outlines the proposed adaptation actions to address the identified vulnerabilities and impacts. It includes specific strategies, programs, and projects to enhance the water sector's resilience.

Chapter eight presents the policy and institutional framework for the sector plan. The framework for monitoring and evaluation is also explained in chapter eight. The chapter also overviews the key implementation challenges and their suggested solutions. The chapter also discusses the key gender considerations for the sector adaptation plan.

The final chapter provides a conclusion on implementing the water sector action plan. Summarise the key findings and recommendations of the plan.

2. Methodology for the Development of the WATER SectoR Adaptation Plan

2.1. Approach

The assessment method for this Climate Change Risk Assessment for the Water Sector followed the top-down assessment, while the adaptation analysis focused on expert reviews and recommendations.

Literature was reviewed to gather secondary data from publications, reports, and conference proceedings as background information for the assessment. Literature focused on review articles on water resources in Ghana and climate change impact and vulnerability assessment at all scales in Ghana. Hazards, vulnerability, and exposure reported in literature formed the basis for data used in the risk assessment.

Information relevant needed for risk analysis was validated by cross-referencing multiple sources outside the country and continent to situate the work in what is scientifically acceptable worldwide. The climate and risk analysis formed the top-down assessment.

2.1.1. Climate analysis

Historical daily rainfall, maximum and minimum temperature data were acquired from the NASA Agroclimatic data platform for the period 1991 – 2020 across the 22 synoptic stations in Ghana, which has been validated in several studies in the country (Larbi et al., 2022, 2021; Bessah et al., 2020, 2018).

Extreme rainfall indices were used, determined, and used as hazards for the climate risk assessment for the water sector. The indices were; Annual total wet-day precipitation (PRCPTOT), Simple daily intensity index (SDII), Number of very heavy precipitation days (R20mm), Max-5-day precipitation amount (RX5day), Consecutive wet days (CWD) and Consecutive dry days (CDD). Trend and extreme indices determination was done for both historical and future periods.

The future assessment focused on the period 2041 – 2070 to conform with the National Climate report of this project. Also, the analysis focused on CMIP5 because of the stability of the downscaled dataset for the Africa region, as stated in the National Climate Report. Two emission scenarios considered were the RCP 4.5 (Mitigation scenario) and RCP 8.5 (Business-as-usual scenario). CCCma-CanESM2 (hereafter referred to as CanESM), HadGEM2-ES (hereafter referred to as HadGEM), MPI-M-MPI-ESM (hereafter referred to as MPI-ESM), and NCC-NorESM1 (hereafter referred to as NorESM) were the GCMs running on CCLM5 at resolution of 22 km available from the Coordinated Regional Climate Downscaling Experiment (CORDEX) project.

2.1.2. Risk Analysis

Risk analysis is a central component of the climate risk assessment process. This stage involves calculating potential hazards associated with extreme climatic events using selected indices and identifying which indices significantly impact critical events such as floods or droughts. The exposure factor in this analysis considers the populations that could be affected by water scarcity or abundance, aligning with the IPCC's methodology for risk assessment. Additionally, land use, land cover, and elevation indices are used to evaluate the vulnerability of different locations to flood or drought events.

The risk analysis depends heavily on the preliminary insights from the synthesis report. Expert consultations are conducted to refine the selection of key variables for the analysis. This collaborative approach ensures the assessment is scientifically sound and culturally relevant. Stakeholder consultations will be conducted to validate the results of the risk analysis, particularly for the identified vulnerable communities or cities.

Engaging stakeholders in this consultation process builds trust and ownership of the findings, increasing the likelihood of support for, and contributions to, the implementation of the recommendations.

2.1.3. Revision and Final Validation

The final step in the climate risk assessment process is revision and validation. This phase refines the assessment findings based on feedback from stakeholders and ensures that the final report is accurate, comprehensive, and ready for action. Stakeholder workshop inputs are carefully reviewed and incorporated into the report, which may involve updating data, revising findings, and integrating new perspectives and insights. The goal is to create a document that accurately reflects the collective expertise of all participants, providing a strong foundation for decision-making.

After these revisions, the report undergoes a final validation process. The updated document is shared with stakeholders for their final review and approval. This step ensures that the report is both technically accurate and aligned with stakeholders' practical needs and priorities. Validation is vital in building consensus and ensuring that the recommended actions are feasible and impactful.

The final report is a strategic tool for policymakers, planners, and other stakeholders. It provides clear recommendations for mitigation and adaptation measures, prioritising actions based on identified vulnerabilities. By incorporating diverse stakeholder inputs and undergoing rigorous validation, the report becomes a credible and authoritative guide for managing climate risks, laying the groundwork for effective implementation and long-term resilience.

2.2. Methodology

2.2.1. Climate Change Risk Assessment

The Climate Change Risk Assessment (CCRA) for the Water Sector adopted a methodology like that of Norman et al. (2014). This methodology is structured into three primary stages, each with its specific focus and activities (see **Figure 1**).

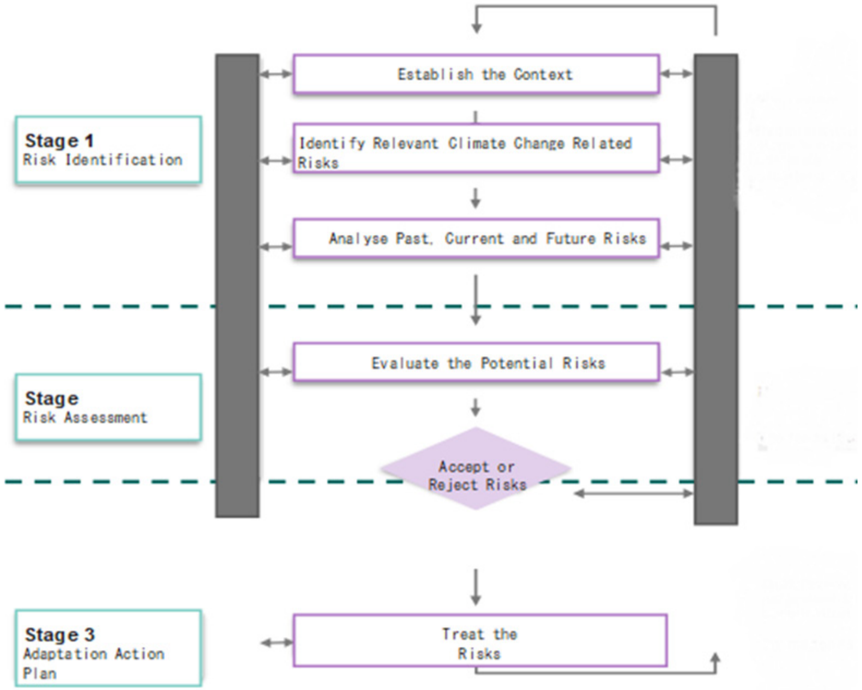
- **Stage 1: Risk Identification** The first step in risk identification for the water sector was gathering the data. This stage involved defining the parameters for hazard, vulnerability, and exposure. Desktop reviews were carried out to reduce the number of parameters to be used for risk identification. These reviews involved examining existing documentation and reports of climate risk assessment of other countries. The 27 extreme climatic indices were determined from the rainfall and temperature (maximum and minimum) records. The risk assessment focused on flood and drought. Therefore, only the extreme rainfall indices were determined as hazards. The same extreme indices were used for the projected climate from 2041 to 2070. After establishing the factors to be adopted as hazards, the number of people per location (population) became the vulnerability and land use land cover and/or digital elevation model was adopted for exposure.
- **Stage 2: Risk Assessment** Risk assessment is the second stage in climate change risk management. Both temporal and spatial risk over the

whole national was carried out in a GIS environment. Understanding the behavior of potential climate risks to the water sector, especially when it comes to floods and drought, aids in the development of appropriate adaptation strategies that will enhance the resilience of individuals and communities. Risk assessment for the historical period (1991 – 2020) before risk assessment for the future period from 2041 – 2070. Identified patterns of risk from the historical to the future help to understand how the risk. Desk reviews were a vital knowledge source in this step. A review of past climate risks in the water sector, especially repetitive events made it easy to draw conclusions on spatiotemporal patterns observed from the results. Experts' engagement ensured that the analysis was comprehensive. The risk management paperwork is informed by the outcomes of the risk assessment. The possible dangers, their effects, and their likelihood are all thoroughly examined in this documentation. It is an essential component in the decision-making process for the acceptance and management of risk.

Risk assessment results are presented in Chapter 5, focusing on climate change's impact on rainfall, evapotranspiration, relative humidity, availability and quality of surface and groundwater, floods, droughts, and sea level rise from literature. The final subsection of the chapter reports on the drought and flood risk analysis unraveling vulnerable locations that must be considered for adaptation implementation. Decisions on where to implement an adaptation action, how and when were derived from the results of the risk assessment.

- Stage 3: Adaptation Action Plan This final stage involved the formulation and implementation of an Adaptation Action Plan to the identified risks. The adaptation action plan's goal is to make sure that the water sector can continue to function efficiently in the face of the identified climate change risks and can withstand the impact of climate change. Treating the risks entails creating and putting into practice plans to control or lessen the hazards that have been identified or building adaptive capacity to reduce vulnerability. The last phase of risk management for climate change is the adaptation action plan.

Figure 1. Methodology for Climate Change Risk Assessment (CCRA) for the Water Sector



(Source: Norman et al., 2014)

The adaptation action plan is a comprehensive document that describes the tactics and steps to be taken in order to control and lessen risks that have been identified. It contains the precise steps, deadlines, roles, and materials needed for execution. In order to determine the efficacy of the measures put into place and make the required modifications, the plan also includes monitoring and evaluation procedures.

The process places a strong emphasis on collaboration and bringing together a range of viewpoints and areas of expertise to inform the assessment and action plan that follows. Contextual appropriate strategy for climate change adaptation for the water sector is key to develop a robust methodology.

2.2.2. Identification and Compilation of Sector-Specific Adaptation Actions

The Water Sector's comprehensive National Adaption Action Plan focused on sector-specific adaption measures. This procedure made it possible to analyze different adaption tactics and determine the best course of action. Adaptation options were determined following the procedure in Table 1.

Table 1 : Methodology to identify adaptation options

Vulnerability assessment report recommendations	The water sector's climate change vulnerability assessment included suggestions for adaptation strategies that may be investigated in order to strengthen resilience, boost adaptive capacity, and lessen vulnerability.
Literature review	A thorough analysis of best practices and solutions was conducted through reviews of scientific reports and publications, government documents, and Metropolitan reports to find adaptation measures that enhance resilience to climate change in the water sector.
Experts' consultation	Experts were identified and engaged on results from the climate risk assessment as well as the projected climate scenarios to discuss the plausible outcomes and suitable adaptation strategies for the water sector.

Source: Author's construct (2024)

Following the creation of a list of possible adaption choices, they were assessed and ranked according to precise standards and information. To evaluate the options' suitability for the water sector, capacity to increase resilience and decrease vulnerabilities was prioritized. The goal of this prioritization method was to make well-informed choices that would prevent maladaptation and promote successful adaptation. Using a Multicriteria Decision Making (MCDM) analysis, the suggested adaption solutions were assessed. This strategy was required since each adaptation metric may have trade-offs and perform differently over a range of criteria. As such, they needed a thorough and critical evaluation, and the analysis's findings had to be incorporated into the process of choosing which possibilities should be prioritized.

Multicriteria Decision Making (MCDM) Analysis is a systematic approach used to evaluate and prioritize multiple options based on various criteria. Table 2 presents the requirements for the evaluation of the climate change adaptation strategies.

Table 2: Criteria for the assessment of the climate change adaptation options

S/N	Dimension	Indicators	Description
1	Technological	Effectiveness	Effectiveness or importance describes how well effective an adaptation option can mitigate climate damage. In essence, an effective option yields considerable benefits in terms of avoided consequences, albeit potentially at a high cost.
2	Economic	Affordability (cost efficiency)	This refers to the cost of implementing the adaptation option
3	Institutional	Institutional feasibility Alignment with district and/or national priorities	Institutional feasibility refers to institutional and legal capacity. The preferred adaptation option aligns with laws, regulations, and institutional structures. The extent to which does this measure supports other development priorities of the district or the country?
4	Technological	Technical feasibility	Technical feasibility focuses on evaluating the technological expertise and the availability of necessary human, financial, and administrative resources for a specific option.
5	Social	Traditional acceptance of adaptation	Traditional acceptance refers to the degree of acceptability of an adaptation strategy aligning with the context of traditional values.
6	Social	Social co-benefits	This entails evaluating whether the proposed adaptation aligns with existing social practices and customs and whether it is likely to be embraced by the affected community or population.
7	Environmental	Flexibility	Flexibility refers to the ability to change behavior in response to changing conditions.
8	Environmental	Environmental considerations	This evaluates the potential of the intervention to improve GHG emissions, biodiversity, human health, soil quality, water quality, air quality, climate, and landscape.
9	Social	Gender responsiveness	This evaluates the extent to which the adaptation options address gender-related issues.
10	Social	Equity	The extent to which the adaptation option will benefit vulnerable groups and communities.
11	Technological	Replicability or scalability	This defines the ability or possibility of the intervention to be replicated elsewhere in the country or scaled up.
12	Technological/ Economic/Institutional /Environmental or social	Barriers to implementation	This identifies potential institutional, economic, technological, and social barriers to the implementation of the adaptation option.

(Source: Dixit and McGray, 2013)

Following the ranking of the various indications, it was crucial to give assign the apropriate weights. According to the relative importance of each indicator, an unequal weighting system was employed (Zobeidi et al., 2024; Antwi-Agyei et al., 2013; UNFCCC, 2011). Similar to Antwi-Agyei et al. (2013), a five-point Likert scale (Table 3) was employed, and experts in field assessed the variables according to their perceived importance (Zobeidi et al., 2024; Antwi-Agyei et al., 2013; UNFCCC, 2011). The weighting mechanism was developed based on the frequency of citations of each indicator.

Table 3: Ranking of adaptation options based

1	Low
2	Neutral
3	Medium
4	High
(….)	Enclose a number in a bracket to show high **uncertainty.**

3. Situation Analysis of the Water Sector

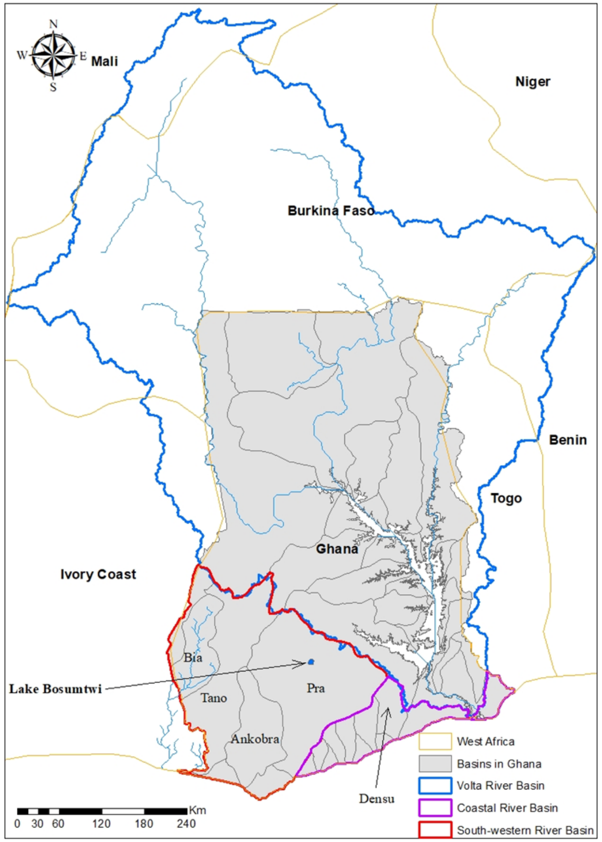
3.1. Background

The water year in Ghana starts on the first day of March each year and ends on the last of February the following year. Officially, the wet season begins on the first day of March, while the dry season ends on the last day of February. However, there are some spatial variations in the hydrological calendar. Total rainfall in the country decreases spatially from 1,800 mm/y on the south-west coast through 1,250 mm/y in the mid belt to about 1,000 mm/y in the north, averaging at about 1,200 mm for the period 1981–2010 (Bessah et al., 2021a). The lowest total rainfall is recorded in the southeast at about 750–850 mm/y (Bessah et al., 2021a). Ghana relies mainly on surface water for domestic (through Ghana Water Company treated supplied water to homes in cities), agricultural and industrial activities, including the generation of electricity (hydropower). Groundwater, especially boreholes, is used for domestic activities in most households across the country but predominantly in the north for agricultural activities through the adoption of dugouts on farms. Both surface and groundwater systems are recharged by rainfall. Evapotranspiration and relative humidity are major climatic factors influencing the distribution and conservation of surface water in Ghana.

3.2. The river systems

Ghana has a land area of approximately 240,000 km^2. The country is endowed with 3 river systems: the Volta River system, the South-western River system and the Coastal River system (Figure 2). The catchment area of the Volta basin extends into 6 riparian countries (Ghana, Burkina Faso, Cote d'Ivoire, Mali, Togo, and Benin), covering a little over 400,000 km2. The main tributaries of the Volta River are the Black Volta, White Volta Red Volta and the Oti rivers. About 85 % of the catchment area of the Volta basin is shared between Ghana and Burkina Faso and 15 % shared between the other 4 countries. The Volta Basin Authority (VBA) was established by the riparian countries to manage the basin as an international resource and by 2010, 5 riparian countries except Cote d'Ivoire signed the VBA agreement bringing the convention into effect. Cote d'Ivoire later joined.

Figure 2: Basin demarcation for the 3 river systems in Ghana



(Source: Agodzo et al. 2023)

The Volta River system drains about 70 % of Ghana's total land area of about 240,000 km2, and the other 2 river systems drain the remaining 30 % in the proportion of 22 % (South-west river system) and 8 % (Coastal river system). Estimated total annual mean runoff for Ghana is about 53.2 - 54.4 billion m^3 of water, of which nearly 40 billion m3, or 68.6 %, is generated within Ghana's borders (WRI, 2010; Agodzo et al., 2014). The remaining 31.4 %, or 15 billion m3, is generated outside Ghana's borders. Some estimates put the annual runoff proportion at 65%, 29% and 6%, respectively, for the Volta, South-western and Coastal River systems (MWRWH, 2007; WRI, 2010; WRC Ghana, 2012). The largest basin in the southwestern river system is the Pra basin, supplying 4 regional capitals and leading producer of tuber crops in the country (Obuobie et al., 2012a; Bessah et al., 2020a). The Densu basin in the coastal river system is of key importance to the water supply in Accra, the capital of Ghana. The Bia River is shared with Cote d'Ivoire, while the lower reaches of the Tano River also form part of the boundary with Cote d'Ivoire (Figure 2). The upper reaches of the Tordzie River in the Coastal system share a boundary with Togo (MWRWH, 2007; Nyatuame et al., 2021).

3.3. Reservoir

Lake Bosomtwi, about 30 km southeast of Kumasi in Ashanti (Figure 2), is a natural lake formed from a meteorite impact. From an aerial view, it looks almost circular, and the crater's rim has a diameter of about 10.5 km. The water surface area, which is below the rim of the crater, is said to have a diameter of 8 km (Koeberl et al., 2007), working out to a surface area of about 50 km^2 and a maximum depth of 78 m (Ministry of Water Resources, Works and Housing, Ghana (MWRWH), 2007). There are 30 settlements dotted around the lake. As shown in Table 2, Lake Volta is a man-made lake and one of the most studied lakes in Ghana (Van de Giesen et al., 2010; Codjoe et al., 2020; Nyadzi et al., 2021). It is the largest impoundment, with a capacity estimated between 148 and 153 km3, when the Akosombo dam was constructed for hydropower generation in 1964 (NASA, 2018).

Other notable artificial reservoirs in Ghana (Table 4) include the Bui reservoir (12.57 km^3), Tono (3.76 km^3), Vea (0.82 km^3), and Kpong (0.23 km^3) [Ministry of Water Resources, Works and Housing, Ghana (MWRWH), 2007; WRC, 2005; Yeleliere et al., 2018] and either used for water supply, irrigation or hydropower generation. The total inland water area, which includes the Volta Lake, Lake Bosomtwi, and others, is about 11,800 km^2 (United Nations Convention to Combat Desertification, 2015). For an average annual rainfall over Ghana between 1,170 and 1,200 mm, the total direct precipitation on the inland water surfaces is ~14 billion m^3 (14 km^3) per annum.

There are smaller impoundments scattered across the country, especially in northern Ghana. Ghansah et al. (2018) studied the small impoundments in the White Volta basin based on remote sensing techniques and ground truthing. They estimated ~254 small reservoirs of surface areas between 1 and 53 ha in the sub-basin. The small reservoirs' combined surface area and volume were estimated to be 1585.265 ha and 21.154 million m^3, respectively.

Table 4: Characteristics of some major reservoirs or impoundments in Ghana and their estimated annual generation rate or irrigation surface or abstraction rate

Location	River	Main Basin	Capacity (106 m3)	Annual energy generated/irrigation aa/rate of abstraction
Akosombo	Volta	Volta	148,000.00	912 MWh
Abesim	Tano	Tano	7.33	2,443,353 m^3/y
Barekese	Offin	Pra	89.59	29,862,840 m^3/y
Bolgatanga	Yaragatanga	Volta	8.10	2,700,000 m^3/y and 450 ha irrigation
Bui	Volta	Volta	12,570.00	400 MWh
Daboase	Pra	Pra	29.88	9,960,120 m^3/y
Hohoe	Dayi	Volta	2.37	788,400 m^3/y
Inchaban	Anankwari	Pra	19.97	6,657,700 m^3/y
Kwanyako	Ayensu	Coastal	14.93	4,977 m^3/y
Kpong	Volta	Volta	160 MWh and 4,000 ha irrigation	
Kpong water works	Volta	Volta	232.59	77,530,000 m^3/y
Koforidua	Densu	Densu	4.97	1,655,640 m^3/y
Weija	Densu	Densu	190.00	
Winneba	Ayensu	Coastal	2.49	829,572 m^3/y
Tamale	Nawusi	Volta	21.41	7,135,721 m^3/y
Tono	Tono	Volta	3,760.27	2,500 ha irrigation
Vea	Vea	Volta	816.00	2,400,000 m^3/y and 1,000 ha irrigation
Owabi	Offin	Pra	15.33	5,109,971 m^3/y

Modified by authors from the Ministry of Water Resources, Works and Housing, Ghana (MWRWH) (2007), WRC (2005), and Yeleliere et al. (2018).

3.4. Wetlands

The discussion here does not include large and small natural and man-made impoundments but is limited to the coastal lagoons, mangroves and the flood plains. Wetlands, which were originally considered "wastelands," have been recognised in Ghana in the context of the RAMSAR convention of 1971 as necessary for providing habitat for wildlife, maintenance of the water table, mitigation of flood conditions, water purification, fishing, hunting, food production, and generation of other economic activities. Public awareness was created on the benefits and functions of wetlands in a coastal Wetlands Management Project undertaken from 1996 to 1999. The notable lagoons (Sakumono, Songor, Keta, Muni-Pomadze) were designated as RAMSAR sites in 1992 [Ministry of Lands and Forestry (MLF), 1999].

Important RAMSAR sites are: Sakumono Lagoon, near Tema in the Greater Accra Region covering 13.64 km^2; Songor Lagoon outside Ada and on the west of Lower Volta River estuary in the Greater Accra Region, covering 28.7 km^2; Keta Lagoon, on the east coast of Ghana, extending about 126 km inland, covering about 1,200 km2; and MuniPomadze Lagoon, west of the coastal town of Winneba, ~55 km west of Accra, covering about 9.5 km^2 [Akyeampong, 2001; Willoughby et al., 2001; Environmental Protection Agency (EPA), 2004; RAMSAR, 2007; Okyere et al., 2012; Adu Kumi and Apraku, 2015; Ramsar Sites Information Service (RSIS), 2022].

The Keta Lagoon is the largest of the 90 lagoons on Ghana's 550 km coastal stretch. The roles these wetlands play in the natural ecosystem functioning include but are not limited to flood attenuation and control, maintenance of underground and surface water supplies, sediment trapping, erosion control, pollution abatement, and provision of habitats of rich biodiversity. In Ghana, they have provided such economic functions as fishing, salt harvesting, water transport, tourism, and water supply (freshwater lakes).

Corcoran et al. (2007) put the total mangrove area in Ghana at 137 km^2. Mangroves are found in nearshore lagoons and estuarine environments. The notable ones are found in the Volta and Densu deltas and the western coastline between Cote d'Ivoire and Cape Three Points on the Western coast of Ghana. Anthropogenic activities have resulted in the harvesting of mangrove wood for fish traps and firewood and have resulted in a drastic reduction in fish stock.

Almost flat and featureless, the flood plains tend to be swampy in the rainy season and stretch from the lowlands of the coastal west to the coastal east and to the foot of the AkwapimTogo ranges. The Keta-Avu plain into which the Tordzie-Aka river discharges is one of the notable flood pains in Ghana, with the heavy clays and serves as an important agricultural area. Logah et al. (2017) did hydrodynamic study impacts of dam water releases from the Akosombo and Kpong hydropower facilities on downstream communities along the Lower Volta River. Combined with some sediment studies, they concluded through simulations that large areas downstream of the dam including its flood plains would be inundated if dam releases came close to or exceeded 2,300 m^3/s, recommending relocation of communities along the banks and in the flood plains of the Lower Volta River.

3.5. Groundwater

Ghana is underlain by three primary geological formations: the basement complex comprising crystalline igneous and metamorphic rocks; the consolidated sedimentary formations underlying the Volta basin (including the limestone horizon); and the Mesozoic and Xenozoic sedimentary rocks. These formations represent 54, 45, and 1% of the country, respectively [(Ministry of Water Resources, Works and Housing, Ghana (MWRWH), 2007; Water Research Institute (WRI), 2010; Water Resources Commission (WRC), 2012a,b)].

The depth of aquifers in the basement complex and the Volta basin is usually between 10 and 60 m, with yields rarely exceeding 6 m^3/h. The aquifer depths in the Mesozoic and Xenozoic formations are generally between 6 and 120 m with average yields of about 184 m3/h, particularly in the limestone aquifer. Groundwater occurrences in limestone formations, which also exist, are much deeper located, typically in the range of 120–300 m. The average yield in the limestone formation is 180 m3/h.

Recharge is usually in the form of direct infiltration of precipitation through fracture and fault zones along the highland fronts and the sandy portions of the weathered zone. Some recharge occurs indirectly as seepage from ephemeral stream channels and pools of accumulated runoff in the rainy seasons. Estimated recharge values are generally low, varying from 1.5 to 19% of annual rainfall, and there is high spatial and temporal variability. Additional recharge occurs through seepage from ephemeral stream channels during the rainy season. There are saline intrusions in shallow aquifers along the coastal zone. At the same time, borehole yields in the Northern, Upper East, Upper West, and parts of Brong Ahafo regions are often insufficient, with some “dry boreholes.” There are also problems with high iron and fluoride content in parts of the country, including the Western, Northern, and Upper East regions (UPgro African Groundwater Country Study, 2020).

Groundwater recharge studies are few. For example, recharge estimates by Obuobie et al. (2012a) in the White Volta River basin of Ghana (~46,000 km^2) for the 2006 and 2007 water years showed high seasonal and spatial variability in the water level, with a range of 1.24–5.00 m in 2006, and 1.60–6.80 m in 2007. Water level rise occurred only in the rainfall season, and recharge to groundwater was estimated to vary between 2.5 and 16.5% of the mean annual rainfall. In another study, Obuobie et al. (2013) assessed the groundwater resource potential for dry-season vegetable irrigation in two areas of north-eastern Ghana. Using geophysical surveying, recharge estimation, and water quality analysis, they found that groundwater abstractions for all purposes are small compared to recharge. Establishing that groundwater was generally suitable for irrigation, they concluded that groundwater use for dry-season irrigation could be expanded 14–18-fold in the study areas.

Ghana shares two principal transboundary aquifers, both coastal and coastal. The Tano aquifer system, located in the extreme southwest of Ghana, is shared between Ghana and Cote d'Ivoire. It covers an area of 806 km^2 in Ghana. It includes three aquifer units (Quaternary, continental terminal and Maastrichtian) and the Keta aquifer system, found in the extreme southeast of Ghana and shared among Ghana, Togo, Benin, and Nigeria. It is a layered system covering an area of 2,721 km^2 (UPgro African Groundwater Country Study, 2020).

3.6. Gender Issues in the Water Sector of Ghana

Climate change impacts on the water sector have distinct implications for different genders and vulnerable groups. Women and youth are particularly vulnerable. Women, who often manage household water needs, face increased hardships when water becomes scarce or contaminated. This burden limits their opportunities for education and economic participation. Youth, especially in rural areas, experience disruptions in their education and future employment prospects due to climate-induced water challenges. Marginalized communities, including those living in poverty or remote areas, are more exposed to climate impacts on water. These groups often have limited access to resources and adaptive capacity, making them more susceptible to water-related disasters. Inadequate infrastructure and services further exacerbate their vulnerability, highlighting the need for targeted support and adaptation measures (Khine and Langkusen, 2023).

Gender-biased Impacts

The impacts of climate change on the water sector are not uniformly distributed; women, youth, and other vulnerable groups often bear the brunt of these effects. Women, in particular, face increased burdens in water collection and management during times of scarcity, which can limit their opportunities for education and economic activities. Additionally, the health impacts of poor water quality and reduced availability disproportionately affect children and the elderly (Updated FRWA Report, 2023). Climate change is increasingly recognized as a critical challenge for water security globally, and its impacts are particularly pronounced along gender lines, exacerbating existing inequalities and creating new vulnerabilities. Understanding the intersection of gender, water, and climate change is essential for developing effective adaptation strategies that address the needs of all community members, especially vulnerable groups.

Climate change affects water availability, quality, and accessibility, which in turn has significant gender implications. Women, particularly in rural areas, are often responsible for water-related tasks, including fetching drinking water, which can become increasingly burdensome as water sources become scarce or contaminated due to climate-induced changes such as droughts, floods, and salinization. These tasks, traditionally assigned to women, can exacerbate gendered vulnerabilities and limit their opportunities for education and economic participation (Sultana, 2018).

The effects of climate change on water security are not uniform but vary across different social strata. Women and marginalized groups often bear the brunt of these changes due to systemic inequities in land ownership, access to resources, and social norms. For instance, during periods of water scarcity, women may spend more time fetching water, which not only impacts their health but also reduces the time available for other productive activities (Sultana, 2018).

Vulnerability and Adaptation

The vulnerability of women and other marginalized groups to climate change is further compounded by their limited capacity to adapt. Adaptive capacity is influenced by access to resources, information, and decision-making power, areas where women and vulnerable groups often face significant barriers. For example, in many developing countries, women have less access to land, credit, and agricultural inputs, which hinders their ability to implement adaptive strategies such as improved irrigation techniques or crop diversification (Sultana, 2018).

Gendered vulnerabilities also manifest in the health impacts of water-related climate change. Women and children are more susceptible to waterborne diseases, which can proliferate with changing climatic conditions that affect water quality. Additionally, the caregiving responsibilities typically assigned to women increase their exposure to health risks during extreme weather events, such as floods and cyclones (Sultana, 2018).

4. National Climate Change Trends

4.1. Country Overview

This section details Ghana's geographical location and profile, its historical climatic condition, and future trends of rainfall and temperature under climate change as it affects the water sector.

4.1.1. Geographic Location

Ghana is bordered by Cote D'Ivoire, Togo, Burkina Faso and the Gulf of Guinea to the west, east, north and south respectively. Agriculture employs 60% of the workforce and contributes about 35% to the national Gross Domestic Product (World Bank Databank 2017). The country is divided into seven agroecological zones based on the climate, natural vegetation and soils. These agroecological zones are Coastal Savannah, Wet Evergreen, Moist Evergreen, Deciduous Forest, Transition zone forest, Guinea Savannah and Sudan Savannah zone. Other agroecological zones classification groups the wet and moist evergreen as a rain forest zone (AQUASTAT Survey 2005).

4.1.2. Country Profile

Ghana has a land area of approximately 240,000 km^2, is situated in West Africa on the Guinea Coast and lies close to the equator on latitude 11.5°N and 4.5°N and longitude 3.5°W and 1.3°E. The Volta River system drains about 70 % of Ghana's total land area of about 240,000 km2, while the southwest and Coastal rivers drain 22 % and 8 % (the remaining 30 %), respectively. The estimated annual mean runoff for Ghana is about 53.2 - 54.4 billion m^3 of water, of which nearly 40 billion m^3, or 68.6 %, is generated within Ghana's borders (WRI, 2010; Agodzo et al., 2014). The depth of aquifers for groundwater sources in the basement complex and the Volta basin is normally between 10 m to 60 m, with yields rarely exceeding 6 m^3 /h. The aquifer depths in the Mesozoic and Xenozoic formations are usually between 6 and 120 m with average yields of about 184m^3 /h. In Ghana, water as an economic good has been considered in all the United Nations (UN) water-related programmes such as the Water and Sanitation Decade, Millennium Development Goals (MDGs), New Partnership for African Development (NEPAD) and now the Sustainable Development Goals (SDGs) in addition to national programmes such as the Ghana Poverty Reduction Strategy (GPRS) (Ministry of Water Resources, Works and Housing (MWRWH), 2007).

4.1.3. Demographic Characteristics

Ghana has a diverse and dynamic population, estimated at over 32 million people, with a relatively young age structure, as nearly 57% of the population is under 25 years old (World Bank, 2024). The country is composed of multiple ethnic groups, including the Akan, Mole-Dagbani, Ewe, and Ga-Dangme, among others, each contributing to Ghana's rich cultural heritage (GSS, 2023). Urbanization is on the rise, with over 56% of the population residing in urban areas, particularly in cities like Accra, Kumasi, and Takoradi, while rural areas still play a significant role in agriculture and local trade. Ghana boasts a relatively high literacy rate compared to other countries in the region, and its demographic distribution supports a growing workforce, which is key to its socio-economic development (GSS, 2023).

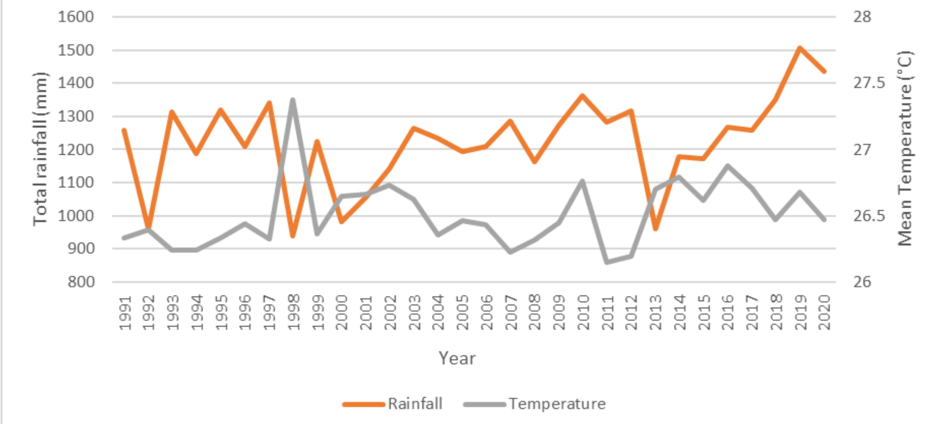
4.1.4. Key Economic Sectors

Ghana's economy is largely driven by key sectors such as agriculture, industry, and services. Agriculture remains a vital part of the economy, employing about 33% of the labour force and contributing significantly to GDP, with cocoa, maize, and yam as staple products (GSS, 2024). The industrial sector, particularly mining and energy, plays a crucial role, as Ghana is a leading exporter of gold and oil. The services sector has expanded rapidly, driven by telecommunications, banking, and tourism, making it the largest contributor to the GDP (World Bank, 2024). Small and medium enterprises (SMEs) also dominate the informal economy, providing employment and supporting livelihoods (GSS,2024). These sectors collectively form the backbone of Ghana's economy, ensuring growth and resilience in the face of global challenges.

4.2. Past Climate Trends

The historical period from 1991 to 2020 recorded a mean annual total rainfall of 1221 mm (940 – 1505 mm) and a mean temperature of 26.5°C (Figure 3). Generally, rainfall and mean temperature showed an increasing trend for the assessed period. The climatology of the country shows that rainfall usually starts in March and ends in July peaking in June at the bi-modal areas (southern) of Ghana as the major season and the minor season starts in September and ends in November. Rainfall onset in Ghana's mono-modal areas (northern) starts in April/May and ends in September every year with specific variations spatially.

Figure 3: Temporal trend of rainfall and temperature for the period 1991 – 2020



4.3. Projected Climate Trends

The assessed models under CMIP 5 showed varying future rainfall trends (2041 – 2070). The mean annual total rainfall under RCP4.5 was 1196 mm, while the ensemble mean of annual total rainfall for RCP8.5 was 1074 mm (Figure 4). Rainfall showed a decreasing trend under both RCP4.5 and 8.5 in the future period.

Spatially, rainfall amounts generally decreased from the north to the south, except for the coast, which recorded a lower rainfall amount compared to the northern part of Ghana (Figure 5). Historical, RCP4.5, and RCP8.5 rainfall amounts were in the ranges of 911 – 1504 mm, 402 – 1605 mm, and 521 – 1737 mm, respectively. Higher rainfall amounts for the historical period were in the south-eastern and central-western parts of the country, while in the future, higher amounts of rainfall were in the south-eastern part, majorly with a decreasing pattern towards the north under RCP8.5 (Figure 5). RCP 4.5 showed a general distribution with spots of higher and lower rainfall in the southern part of the country. The future rainfall amount showed a change in the range of -785 to +417 mm under RCP4.5 and -556 to 362 mm under RCP8.5 emission scenarios (Figure 5).

Figure 4: Temporal trend of total rainfall from historical (reanalyzed) and CMIP5 CORDEX CCLM5 models at 22 km spatial resolution

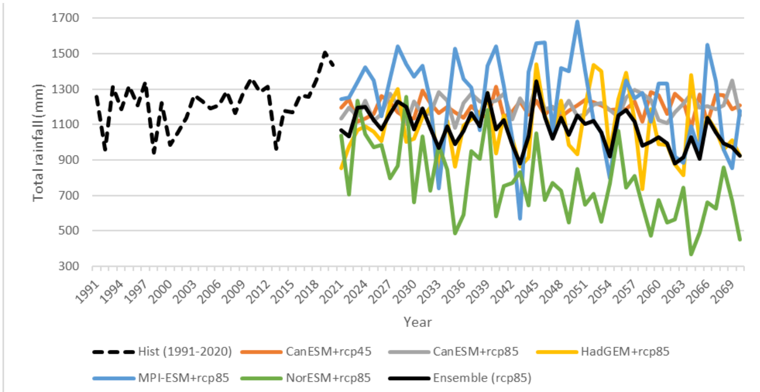
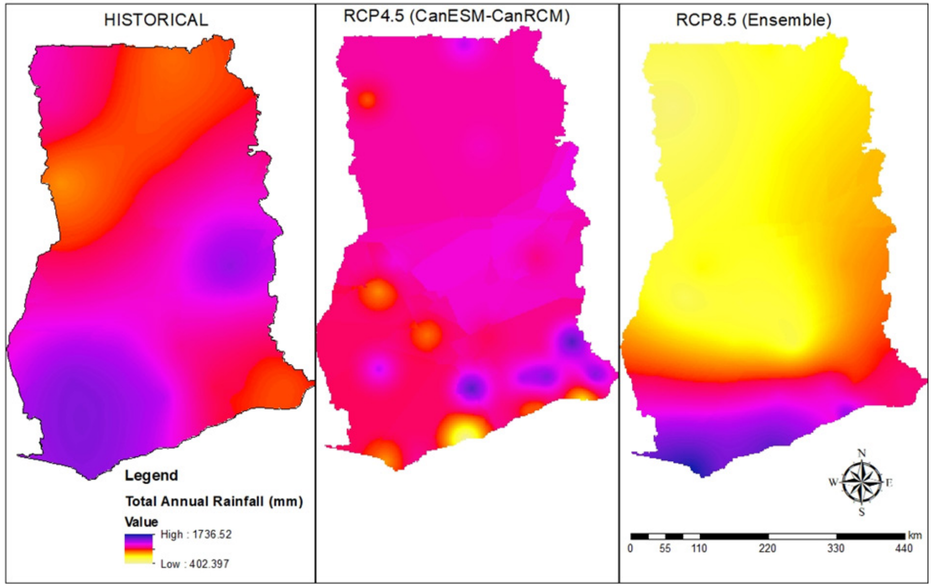


Figure 5: Spatial distribution of total rainfall



The average mean temperature of 26.5°C in the historical period increased by 0.74°C and 1.01°C under RCP4.5 and 8.5 in the future (Figure 6). Spatially, maximum temperature increases northward both in the historical and future period of assessment (Figure 7). The trend shows increased coverage of high maximum temperature from the central part of the country to the south. Maximum temperature in the range of 28 – 34°C in the period 1990 – 2020 could increase to 29 - 37°C in the future period (Figure 7). The spatial trend of minimum temperature was an increase southward. The change in minimum temperature was more profound in the future under RCP8.5 (23 - 26°C) from historical values in the range of 22 - 25°C (Figure 8). There was a spatial change in minimum temperature under RCP4.5, but the values or range were the same as the historical.

Figure 6: Temporal trend of mean temperature from historical (reanalyzed) and CMIP5 CORDEX CCLM5 models at 22 km spatial resolution

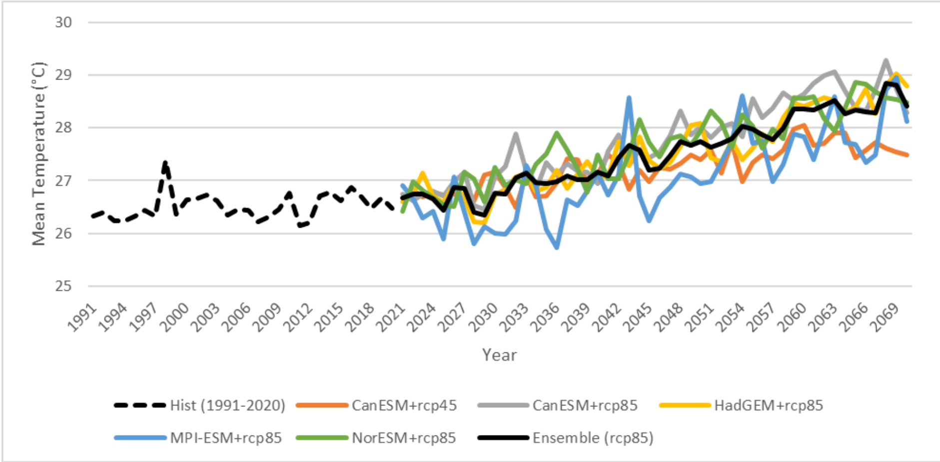


Figure 7: Spatial distribution of maximum temperature

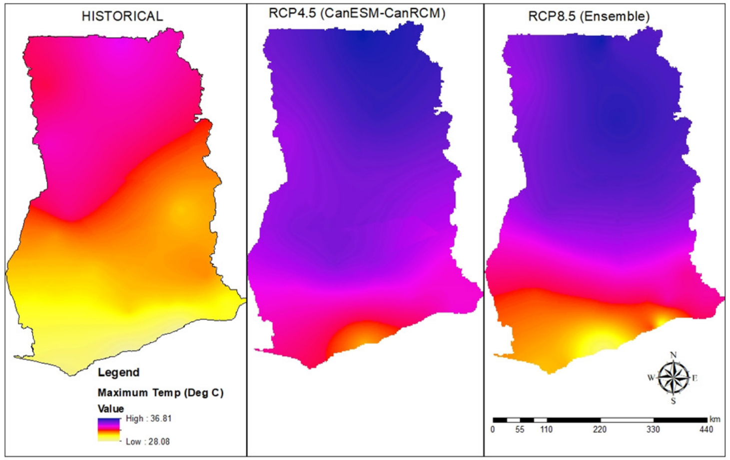
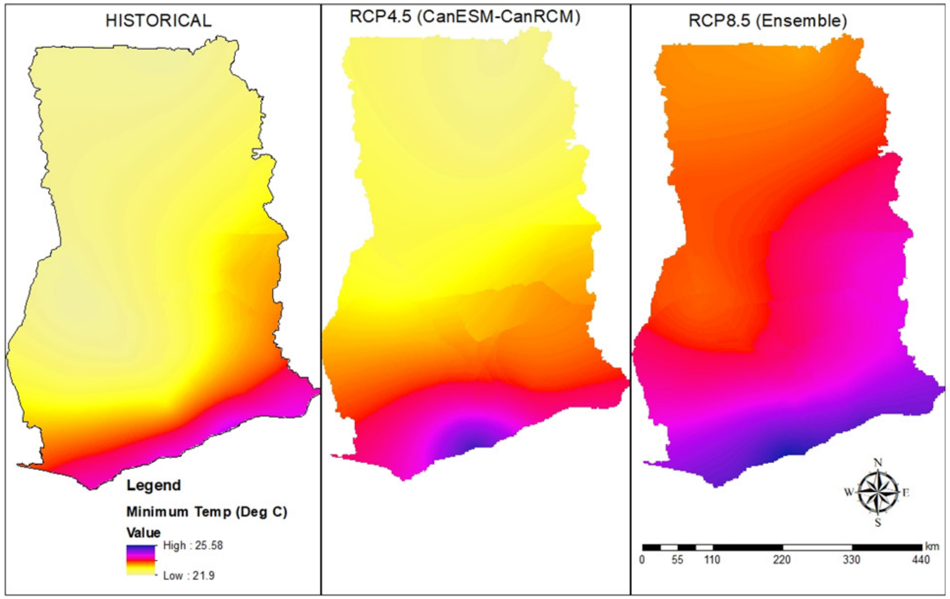


Figure 8: Spatial distribution of minimum temperature



5. Climate Change Impacts and RISK Analysis of the Water Sector

5.1. Impacts of Climate Change on Rainfall, Evapotranspiration, and Relative Humidity

Several studies have concluded that the length of the rainfall season has been changing with delayed onset and early cessation of the rains. This is affecting agricultural production a great deal. This has led to mitigation measures such as the breeding of short-duration and drought-resistant crop varieties in order to cope with the changes in the length of the rainfall season (e.g. Omotosho et al., 2000; Kumi and Abiodun, 2012; Amekudzi et al., 2015). Some rainfall-related studies were about rainfed agriculture, with reference to rainfall onset, cessation and length of rain days (Table 5).

Logah et al. (2013) surveyed 77 meteorological stations in Ghana and showed that there had been a general decline in the distribution of rainfall in the entire country. This trend, they attributed to such anthropogenic activities as deforestation, poor farming practices, overgrazing, harvesting wood for energy and bushfires. Some other studies (e.g. Ampadu, 2008; Ampadu et al., 2019) were localised and mostly came up with similar conclusions on rainfall, even though some showed some increasing trends.

The potential crop evapotranspiration for rice, tomato, and pepper was estimated as 697, 533, and 427 mm/season, respectively (Sadick et al., 2014). Aidoo et al. (2021) also argued that climate change is having an adverse effect on the environment, especially in sub-Sahara Africa, where the capacity for natural resource management, such as water, is very low. They considered water loss from the environment in the form of evapotranspiration (ET) as a major component in the hydrological cycle. Understanding its spatial dimensions is critical in evaluating its effects on regional land use, thus employing the METRIC method to create an evapotranspiration map for land use in the Kintampo North Municipal area for Ghana.

Table 5: Selected impacts of climate change on climatic parameters

SN	Location	Impact	Reference
1	Volta River Basin	The annual decrease in precipitation under RCP4.5 and 8.5 in the 2020s, 2050s, and 2080s and a relative increase from late November to January.	Yeboah et al. (2022)
2	Ashanti Region	a unit increase in RH could result in a 0.001 t/ha decrease in maize and a 1.219 t/ha increase in cassava, while a unit decrease in RH could increase yam yield by 0.385 t/ha.	Dwamena et al. (2022)
3	Oti River Basin	Increased variability in rainfall onset (128 – 144 days) and cessation (302 -280 days) from 2021 – 2050	Kwawuvi et al. (2022)
4	Ghana	10 – 40 % and 8 – 38 % increase in rainfall amount under RCP4.5 and RCP8.5 emission scenarios of SDSM	Bessah et al. (2021a)
5	Pra River Basin	Both increase and decrease in the length of the rainy season from different climate models from 2020 - 2049	Bessah et al. (2020)
6	Tordzie basin	6.3% increase in ETo by 2050	Nyatuame et al. (2020)
7	Ghana	Low rainfall amount (decline) the the 2020s, 2050s and 2080s	Asante and Amuakwa-Mensah (2015)

5.2. Impacts on Surface and Ground Water Quality

Water quality studies are many, but there is hardly any long-term water quality data (Ansa-Asare, 2006; Leslie, 2010; Bessah et al., 2021b). Most water quality studies have reported testing occasional samples taken from surface sources. The non-regular water quality tests have mostly been blamed on financial constraints, but the difficulty of such data is that it does not tell the full story of the changes occurring in the water quality for informed management decisions to be made.

The most authentic studies based on regular rather than occasional water sampling were observations of weekly bacterial counts throughout the water column of the Volta Lake at Ajena (a lake shore settlement) from August 1964 to December 1965. The results showed that during the rainy season, bacterial populations increased, the contrary being true in the dry months (Biswas, 1967). Goski (1999), Karikari and Ansa-Asare (2006), Asamoah-Boateng (2009), Leslie (2010) and Cobbina et al. (2010) reported on biological quality of dugout and river water sources indicating high bacterial contamination in some cases and recommending treatment for such waters if they were to be used for domestic purposes.

Mining activities in the south-western river system (Pra, Tano, Birim, Offin, Bia, Ankobra) of Ghana have also attracted a lot of attention, where mining-related chemical contamination of such surface and groundwater sources have become a significant concern (Table 6). Other chemical contaminants reported have been total dissolved solids (TDS), total hardness, and Biological oxygen demand (BOD), while turbidity, colour, and total suspended solids have been some of the physical parameters investigated in water bodies in Ghana (Yeleliere et al., 2018).

Nkansah et al. (2010), Affum et al. (2015) and Saana et al. (2016), based on occasional water sample tests, reported on biological water quality of some groundwater sources, indicating the absence of and excesses of bacterial contamination depending on the sources of water. Groundwater abstracted from boreholes in Ghana is generally of good chemical and microbiological quality and thus suitable for domestic (including drinking), agricultural and industrial uses. However, in the forest zones of southern Ghana, groundwater has a low pH (3.5-6.0). High concentrations of iron are found in many places throughout the country. High natural concentrations of manganese and fluoride are found mostly in the northern regions. High levels of mineralization, with total dissolved solids (TDS) in the range of 2000 up to more than 14,000 mg/l, are found in some coastal aquifers, largely due to high salt (sodium chloride) from seawater intrusion (UPgro African Groundwater Country Study, 2020).

Possible point source pollution sources include refuse dumps and latrines. For example, Anim-Gyampo et al. (2020), in a study of the Atankwidi catchment (191.27 km^2) of the White Volta Basin, found that 20, 48.8 and 33.2 % of the basin showed low, moderate and high risks, respectively of groundwater contamination, attributing the level of vulnerability to the depth to the groundwater table. The least thickness of the vadose zones showed high risks, while the greatest thickness of the vadose zone showed low contamination risks, with about 80% of the entire Atankwidi catchment showing moderate to high risk of groundwater pollution.

Table 6: Some reported heavy metals in mining areas and river basins in Ghana

SN	Location	Levels of heavy metals	Reference
1	Newmont Ghana Gold Mining concession areas	Predominant heavy metals in water bodies were arsenic (As), iron (Fe) and lead (Pb)	Asamoah-Boateng (2009)
2	Bibiani	As (<0.001–0.002 mg/), Cu (0.002–0.04 mg/l), Mn (0.10–0.72 mg/l) and Fe (0.32–3.04 mg/l)	Asante (2012)
3	Pra River Basin	Sedimentation yield and bank erosion	Kusimi (2014)

4	Pra River Basin	As (0.002 – 294.429 µg/l); Cd (0.001 – 1.366 µg/l); Cu (0.036 – 403.787 µg/l); Fe (0.125 – 429.145) mg/l); Hg (0.005 – 7.566 µg/l); Pb (0.018 – 68.451 µg/l)	Bessah et al. (2021b)

5.3. Floods

Flood is an uncertainty and historical response to responding to such uncertainty has included improving knowledge about the uncertainty and the construction of engineering structures to contain the flood (Hirsch, 2011; Galloway, 2011). The maximum daily rainfall over Accra (244 mm) and Kumasi (168 mm) for the period 1960 - 2017 saw an increasing trend of the same over the period in Accra and a decreasing trend in Kumasi (Ansah et al., 2020). These daily maximum rainfall events were flood-related events. Most of the rainfall studies in Ghana are flood-related (eg. Owusu-Ansah, 2016; Amoako and Inkoom, 2018; Owusu-Ansa et al., 2018; Frick-Trzebitzky and Bruns, 2019; Mensah and Ahadzie, 2020; Ansa et al., 2020). Between 2000 and 2020, there were 17 recorded flood events (Table 7) in Accra alone (Mensah and Ahadzie, 2020). Seventeen (17) annual events in a period of 20 years could well be described as nearly yearly flood events. Mensah and Ahadzie (2020) attributed the floods to poor urban planning and development, poor and inadequate drainage infrastructure, poor environmental attitude of the citizenry and extreme rainfall events. These floods led to physical, economic, social and ecological costs. Displaced people depended on government, friends and family support and the construction of new drains and desilting and cleaning of drains were remedial measures.

It is common knowledge that hydraulic structures are designed based on peak flood estimates. However, such hydraulic structures sometimes burst their seams in extreme rainfall conditions. In urbanisation, hard surfaces have increased in the form of pavements, thereby increasing surface runoff into the drains. Urban drains in Ghana have been overwhelmed by the poor environmental practices of the citizenry of Ghana. However, flood events have increased in magnitude, frequency, duration, and severity in Ghana due to climate change (IPCC, 2012; World Bank, 2011). Thus, flood risk management (FRM) regimes and sustainable adaptation approaches are urgently needed. Rain et al. (2011) and Appeaning-Addo et al. (2011) have attributed flooding occurrences to climate variability and change. The changes in climatic conditions coupled with rapid urbanization modify the natural hydrology of the country, resulting in heavy precipitation and increasing peak run-off discharge (Nyarko, 2002; Adank et al., 2011), leading to flush floods. The probabilistic risk profile of Ghana indicates that the country loses 200 million dollars annually due to floods and droughts. In technical terms, under the current climate and considering the frequency of floods, this average annual loss could well be more than 200 million dollars per annum. The United Nations Office for Disaster Risk Reduction (UNISDR) Regional Office for Africa, projecting into 2050, predicted a 5-fold increase in floods. This will adversely affect the potential GDP growth of the country (UNISDR, 2018).

Table 7: Some major floods in Ghana

Year of reported major flooding	Region (city)
2000	Central (Cape Coast)
1968, 1997, 1986, 1999, 2001, 2002, 2003, 2004, 2005, 2007, 2008, 2009, 2010, 2011, 2013, 2014, 2015, 2016, 2017, 2018, 2019	Greater Accra (Accra)
2010	Volta (Keta)
2010	Eastern (Kwahu)
2002, 2012	Central (Kasoa, Swedru)
2018	Northern (Buipe)
1971, 2002	Western (Sekondi-Takoradi)
2004, 2018	Ashanti (Kumasi)
2005	Central (Saltpond)

2007	Upper East (Bolgatanga)

(Source: Mensah and Ahadzie, 2020)

Some major floods in Ghana

5.4. Droughts

Drought connotes the absence of water and is defined specifically by the nature of the hazard it causes and its variation in frequency from region to region. Wilhite et al. (2007), cited by Nasirudeen et al. (2021), identified four main types of drought meteorological, agricultural, hydrological and socio-economic. Table 8 presents some selected drought events in Ghana.

Few studies sought to analyse drought patterns within specific basins in Ghana, and most of the hydrological studies are centred around the black and white Volta basins (e.g. Kasei et al., 2010; Ndehedehe, 2016). According to Nasirudeen et al. (2021), these studies, however, do not analyse the drought profile within these basins. Nyatuame and Agodzo (2017) also analysed extreme rainfall events (drought and flood) over the Tordzie watershed in the Volta Region of Ghana, which is in the coastal river basin. Tordzie is a transboundary basin shared between Ghana (1865 km^2) and Togo (363 km^2). Drought analysis based on 3, 6, 9, and 12–month time scales showed that drought intensity was inversely proportional to its duration, meaning that as drought frequency increased, its corresponding duration decreased.

Table 8: Selected drought events in Ghana

SN	Period	Description	Reference
1	1983, 1992 and 2001	Meteorological drought in Ghana resulting from rainfall less than 900 mm per annum	United Nations Convention to Combat Desertification (2015)
2	2001, 2007 and 2013-2014	Hydrological droughts in Ghana that affected water levels in the Akosombo, Kpong and Bui reservoirs	United Nations Convention to Combat Desertification (2015)
3	1980 - 2014	Moderate to severe meteorological drought in coastal towns (Axim, Takoradi, Saltpond, Accra, Tema, Ada) during the dry seasons	Addi et al. (2021)

5.5. Sea Level Rise

Sea-level rise poses a significant risk to coastal aquifers due to saltwater intrusion, which can contaminate freshwater supplies. This is particularly problematic for communities that rely on coastal aquifers for their drinking water and agricultural needs. The encroachment of saltwater into freshwater systems can lead to the loss of arable land and negatively impact food security (Ghana Water Policy, 2024). Sea level rise is one of the most significant and visible effects of climate change. The global average sea level has risen approximately 8–9 inches (21–24 cm) since 1880, with an accelerating rate of increase in recent years. This phenomenon poses critical risks to both human populations and natural ecosystems, especially in coastal areas.

Historical and Recent Trends

Since 1880, the global average sea level has increased by 8–9 inches (21–24 cm). In 2022, the global average sea level reached a new record high, 101.2 mm (4 inches) above the 1993 levels. The rate of sea level rise has more than doubled from 0.06 inches (1.4 mm) per year throughout most of the twentieth century to 0.14 inches (3.6 mm) per year from 2006–2015 (Lindsey *et al.*, 2022). These increases are primarily driven by the melting of glaciers and ice sheets, as well as the thermal expansion of seawater as it warms.

Regional Variability

Sea level rise is not uniform across the globe. In some ocean basins, sea levels have risen by as much as 6-8 inches (15-20 cm) since the start of the satellite record in 1993. Factors such as local land subsidence, upstream flood control, erosion, regional ocean currents, and the post-glacial rebound of land masses contribute to regional differences. In the United States, the fastest rates of sea level rise are observed in the Gulf of Mexico and the mid-Atlantic regions, while some areas in Alaska and the Pacific Northwest have seen falling sea levels due to geological processes, although this trend is expected to reverse with continued high greenhouse gas emissions (Lindsey *et al*., 2022).

Implications for Coastal Areas

Coastal areas are high population density locations where sea level rise exacerbates flooding, shoreline erosion, and storm hazards. Eight of the world's ten largest cities are globally near coastlines, making them particularly vulnerable. Rising sea levels threaten critical infrastructure, including roads, bridges, subways, water supplies, power plants, and sewage treatment plants. Increased background water levels mean that storm surges from extreme weather events can push further inland, causing more damage (Lindsey *et al*., 2022).

Environmental Impacts

Rising sea levels stress coastal ecosystems that provide vital services such as storm protection, recreation, and habitats for fish and wildlife, including commercially important fisheries. Saltwater intrusion into freshwater aquifers further compromises municipal and agricultural water supplies and natural ecosystems (Lindsey *et al*., 2022).

Future Projections

Projections for future sea level rise depend largely on the trajectory of greenhouse gas emissions and the response of major ice sheets. Even with significant reductions in emissions, the U.S. Sea level is projected to be around 0.6 m (2 ft) higher on average by 2100 compared to 2000 levels. In scenarios with high emissions and rapid ice sheet collapse, sea levels could rise by 2.2 meters (7.2 feet) by 2100 and up to 3.9 m (13 feet) by 2150 (Lindsey *et al*., 2022).

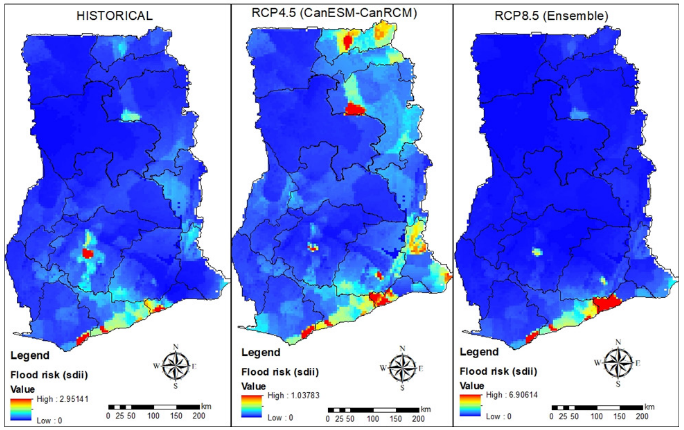
Socioeconomic Impacts

Economic costs associated with sea level rise are substantial, including damages to infrastructure, increased costs for coastal protection, and losses in property values. Socially, vulnerable populations such as low-income communities, women, and youth are disproportionately affected. Women, who often manage household water needs, face increased hardships with water scarcity, while youth in rural areas experience disruptions in education and employment prospects. Marginalized communities, with limited access to resources and adaptive capacity, are more susceptible to the adverse effects of sea level rise (Lindsey *et al*., 2022).

5.6. Flood and Drought Risk Analysis of the Sector

Flood risk was determined with the Annual maximum consecutive 5-day precipitation in millimetres. According to Ansah et al. (2020), about 244 mm in Accra increased flood events between 1960 and 2017. Using that as a benchmark for potential flood events from the maximum consecutive 5-day precipitation, which was about 71 – 108 mm, 59 – 244 mm, and 82 – 208 mm for the historical period (1991 – 2020), RCP4.5 (2041 – 2070) and RCP8.5 (2041 – 2070) emission scenarios respectively indicate the plausibility of increased flood in flood-prone zones in Ghana due to climate change (Figure 9). The simple daily intensity index (SDII, Appendix II), which is the Annual total precipitation divided by the number of wet days (PRCP ≥ 1 mm), can also be used to monitor extreme rainfall events and flooding. In the historical period, SDII was between 4.57 and 6.39 with the potential to increase in the range of 4.25 – 6.93 and 4.83 – 8.19 under RCP4.5 and 8.5 in the future respectively. This calls for intentional and immediate adaptation planning and implementation to secure communities and properties from damage in the future across flood-prone zones in Ghana.

Figure 9: Flood risk map of Ghana based on SDII hazard

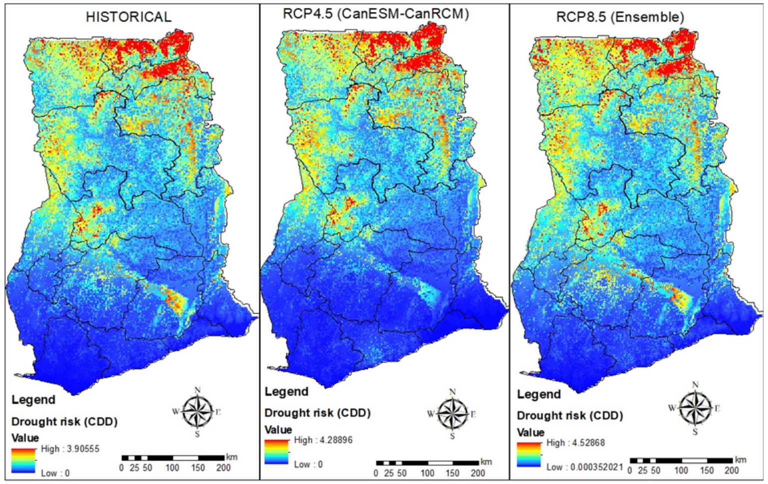


Flood risk in Ghana during the historical period was low (0 – 2.95) with the potential of increasing to high (0 – 6.9) in the future under RCP 8.5 (Figure 9). Possible affected areas to be considered for adaptation are Northern (Tamale), Ashanti (KMA, Suame, Kwadaso, Oforikrom, Asokore Mampong, Asokwa, Old Tafo), Eastern (New Jauben), Western (Efia Kwesimintsim, Sekondi-Takoradi, Shama), Central (all districts along the coast, especially Cape Coast and Effutu) and Greater Accra (all districts except Ada, Shai Osudoku, Ningo/Pampram). These locations have been experiencing floods in the past (Mensah and Ahadzie, 2020). Adopting a combined hazard of consecutive wet days, simple daily intensity index and annual maximum consecutive 5-day precipitation showed concentrated potential floods in the coastal zone of Ghana in the future (Appendix IV).

Consecutive dry days (CDD) is an extreme climatic index to monitor drought and dry spell events (Appendix III). CDD is the maximum number of consecutive days with precipitation less than 1 mm. It can be used to determine the water stress levels of an environment. The maximum historical consecutive dry days was about 14 - 115 days and could increase to 39 - 134 days in the future under RCP 8.5.

According to Addi et al. (2021), drought in Ghana is in the range of moderate to severe. Flood risk results showed similar findings across the nation (Figure 10). Drought risk in the historical period was moderate (0 – 3.9) and could increase but within the same moderate range (0 – 4.5) in the future under the RCP8.5 emission scenario. Regions with potential drought risk beyond 3.0 are North East (4.52), Upper East (3.90), Oti (3.80), Volta (3.60), Upper West (3.28) and Bono East (3.20) (Figure 10). Adaptation planning should target these regions for stakeholder consultation and engagement to enhance resilience and reduce shocks without neglecting drought-prone zones like the Savanna and Northern regions.

Figure 10: Drought risk map of Ghana using CDD as the climatic hazard



6. Proposed Adaptation Actions for the Water Sector

This section outlines the proposed adaptation actions to address climate change risks in the water sector. These actions are designed to address the vulnerabilities and enhance the resilience of the water sector in Ghana.

6.1. Nature-Based Adaptation Actions

Nature-based adaptation strategies harness the power of natural ecosystems to mitigate the impacts of climate change while enhancing resilience for both human and ecological systems. These approaches work with nature to deliver multiple co-benefits, such as boosting biodiversity, strengthening ecosystem services, and supporting livelihoods, particularly in rural or vulnerable communities. In addition to being cost-effective and sustainable, these solutions contribute to long-term climate resilience by promoting ecological balance and fostering environmental stewardship.

6.2. Technological and Engineering Measures

Technological and engineering measures focus on utilising innovation and scientific principles to adapt to climate change challenges. These interventions are grounded in precision and efficiency, encompassing a wide spectrum of solutions, from large-scale infrastructure projects, such as flood barriers and coastal defences, to smaller-scale technologies to improve resource management, monitoring, or early warning systems. By leveraging advancements in science and engineering, these measures offer reliable and impactful tools for managing climate risks and safeguarding communities.

6.3. Policy Measures

Policy measures establish the institutional and governance framework necessary to enable climate adaptation. These mechanisms include policies, laws, strategies, and programs that integrate adaptation actions into national development goals and align them with international climate commitments. By addressing barriers such as financial constraints, knowledge gaps, or lack of coordination, policy measures create an enabling environment for adaptation. They provide incentives, build capacity, allocate resources efficiently, and foster stakeholder collaboration. Furthermore, they ensure systematic monitoring and evaluation of adaptation efforts, paving the way for scalable and sustainable climate resilience.

Table 9: Tall list of adaptation actions for the water sector

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Nature-Based Solutions		
Implement rainwater harvesting systems to capture and store rainwater for irrigation, reducing reliance on groundwater and improving water availability during dry periods.	Deploying advanced water monitoring systems improves the detection of pollutants and helps maintain safe water standards. In Ghana, real-time monitoring of water bodies can enhance public health by reducing waterborne diseases and protecting aquatic ecosystems.	National Climate Change Policy (2015)
Promote wetlands and riparian buffers to filter agricultural runoff, reduce sedimentation, and improve water quality.	Implementing IWRM ensures coordinated management of water, land, and related resources to maximise economic and social welfare without compromising ecosystem sustainability. In Ghana, IWRM can help balance competing demands for water resources, improve water governance, and enhance resilience to climate change impacts on water availability.	Planting for Food and Jobs (PFJ)
Adopt soil and water conservation techniques, such as contour bunding and terracing, to minimise surface runoff and enhance groundwater recharge.	Strengthening community participation in water governance empowers local stakeholders to manage water resources sustainably. In Ghana, this approach can foster equitable access to water, reduce conflicts, and enhance the long-term sustainability of water infrastructure and resources.	Ghana Irrigation Development Authority (GIDA)
Encourage using vegetative cover (cover crops or green cover) to reduce soil erosion, improve moisture retention, and increase water infiltration.	Adopting advanced water conservation technologies, such as rainwater harvesting and smart irrigation systems, enhances water availability for multiple uses, including domestic, agricultural, and industrial applications. In Ghana, these technologies can significantly reduce water wastage, improve access to clean water, and mitigate the effects of water scarcity, especially in drought-prone regions.	Farmer Cooperatives

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Introduce water-efficient irrigation systems, such as drip and sprinkler systems, to optimise water use and reduce waste.	Integrating trees and shrubs into livestock farming enhances soil water retention, reduces surface runoff, and improves microclimatic conditions. Shade from trees reduces water consumption by livestock due to lower heat stress. In Ghana, silvopastoral systems can increase water-use efficiency, enhance ecosystem services, and improve farm productivity.	Food and Agriculture Sector Development Policy (FASDEP)
Promote agroforestry and buffer zones along waterways to reduce water pollution from agricultural fields and enhance biodiversity.	Implementing water harvesting systems, such as ponds and storage tanks, ensures a steady water supply for livestock, even during dry seasons. In Ghana, where water scarcity affects rural areas, such technologies enhance resilience, reduce dependency on seasonal rainfall, and secure livestock hydration and health.	Seed Act, 2000 (Act 576)
Restore and conserve natural water bodies and watersheds to improve water storage capacity and enhance ecosystem services for water regulation.	Efficient watering systems, such as automatic drinkers and controlled water delivery systems, optimise water use and reduce wastage. In Ghana, adopting these systems increases water-use efficiency, decreases labour demands, and promotes sustainable livestock farming practices	Ghana Climate Change Gender Action Plan
Use mulching and other ground cover techniques to reduce evaporation, conserve soil moisture, and improve water-use efficiency.	Improved housing designs minimise water needs for cooling and reduce heat stress-related dehydration in animals. This results in better productivity and reduced water wastage. In Ghana, such interventions can enhance livestock production, mitigate losses, and improve farmer incomes by ensuring healthier animals.	Ghana Climate Change Policy (2013)
Encourage the integration of climate-smart agricultural water management practices, such as alternate wetting and drying in rice cultivation, to optimize water use.	Climate-related risks often lead to water scarcity, affecting livestock productivity. Insurance schemes mitigate financial losses due to water-related issues, ensuring farmers remain resilient. In Ghana, such schemes improve financial security, enable recovery from water shortages, and encourage farmers to adopt sustainable water management practices.	Integrated Water

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Rehabilitate degraded landscapes and create green corridors to improve water retention, prevent flooding, and enhance resilience to climate change impacts.	Marine Protected Areas (MPAs) help restore critical habitats, boost biodiversity, and enhance fish populations, ensuring sustainable fisheries. In Ghana, establishing MPAs can protect valuable fish breeding grounds, support the recovery of degraded ecosystems, and increase long-term fish yields. These benefits foster resilience against climate-related disruptions, improve food security, and create livelihood opportunities for coastal communities.	Resource Management (WRC, 2012)
Promote soil organic matter enrichment to improve soil structure and water-holding capacity, reducing irrigation needs.	Breeding fish species that can withstand temperature fluctuations ensures fish populations can thrive in changing ocean conditions. In Ghana, where rising sea temperatures impact traditional fisheries, adaptive breeding programs can safeguard fish stocks, enhance food security, and reduce vulnerability to climate change. Additionally, these programs encourage innovation and research in sustainable aquaculture practices.	Community Water and Sanitation Agency
Develop water-efficient livestock breeds that require less water while maintaining productivity and resilience to heat stress in tropical environments.	Implementing advanced marine monitoring systems, including satellite and drone technologies, enables real-time tracking of fish populations and environmental conditions. In Ghana, such systems provide crucial data for proactive fisheries management, improving resilience to climate-induced shifts and ensuring sustainable fishery practices that can withstand future challenges.	Ghana Climate Change Policy (2013)
Promote drought-tolerant forage species to ensure a sustainable and reliable feed supply for livestock during periods of water scarcity.	Strict regulation enforcement helps combat overfishing and illegal fishing practices threatening marine ecosystems. By ensuring sustainable fishing practices, Ghana can preserve fish stocks, protect biodiversity, and ensure a steady supply of fish for local communities. Strengthened regulations will contribute to long-term fisheries sustainability and enhance climate resilience.	Livestock Development Policy and Strategy (2016-2025)

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Establish silvopastoral systems incorporating trees, shrubs, and grasses to provide shade, reduce heat stress, and improve water retention in grazing areas.	Empowering local communities through participatory fisheries management strengthens adaptive capacity and promotes sustainable resource use. In Ghana, community-based management programs help local fishers monitor fish stocks, enforce sustainable practices, and engage in climate adaptation strategies. This approach enhances resilience to environmental changes and supports livelihoods in fishing-dependent regions.	National Irrigation Policy
Implement rotational watering systems to optimise the sustainable use of limited water resources in livestock management.		National Biodiversity Strategy and Action Plan (2016-2020)
Enhance pasture water retention capacity through planting deep-rooted grasses and legumes that improve soil structure and water infiltration.		Animal Health and Production Policy (2016)
Promote riparian buffer zones along water bodies to protect water quality from livestock-related contamination and reduce erosion.		Ghana Shared Growth and Development Agenda (GSGDA)
Encourage integrated watershed and grazing land management to maintain water balance, reduce runoff, and enhance aquifer recharge.		National Adaptation Plan Framework (2018)
Adopt natural water catchment systems to collect and store rainwater for livestock use during dry seasons.		Forestry Development Master Plan (2016-2036)
Restore degraded rangelands with drought-resistant vegetation to enhance groundwater recharge and mitigate water loss.		Planting for Livestock and Jobs Program
Use mulch and organic soil amendments to improve soil moisture retention in livestock grazing zones.		Sustainable Land and Water Management Project (SLWMP)
Implement marine protected areas and freshwater reserves to safeguard critical fish habitats, breeding grounds, and nursery zones from overfishing and habitat degradation.		Ghana National Fisheries and Aquaculture Policy (2008)
Promote sustainable aquaculture practices by diversifying climate-resilient fish species and integrating natural vegetation to improve water quality and reduce vulnerability to extreme weather events.		Fisheries Act, 2002 (Act 625)

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Develop climate-adaptive fish breeding programs to focus on temperature-tolerant and drought-resistant species that can thrive in changing water conditions.		National Climate Change Policy (2013)
Establish fish gene banks to conserve genetic diversity, ensuring future access to resilient fish strains for restocking programs.		Ghana Marine Pollution Act (2016)
Create ecosystem restoration strategies targeting degraded mangroves, coral reefs, and wetlands to improve natural fish habitats and enhance coastal resilience.		Coastal Development Strategy (2013)
Develop marine biodiversity conservation frameworks that protect vulnerable and endangered fish species from climate-induced threats.		Ghana Biodiversity Strategy and Action Plan (2016-2020)
Implement community-based fish breeding, restocking programs, and fisheries co-management models to restore fish stocks and foster sustainable fishing practices.		Fisheries Management Plan of Ghana (2015-2019)
Enhance biodiversity through habitat improvement projects such as artificial reefs, seagrass planting, and riverbank vegetation.		Environmental Protection Agency Act (1994)
Support wetland preservation and sustainable watershed management to maintain healthy freshwater ecosystems for inland fisheries.		Ghana Aquaculture Development Plan (2012-2017)
Promote nature-based solutions for water quality enhancement by integrating floating wetlands and buffer zones to filter pollutants and reduce the impact of agricultural runoff on aquatic habitats.		Ghana's National Adaptation Plan Framework (2018)
Technological/Engineering Measures		
Develop and implement water-efficient irrigation systems, such as drip and micro-irrigation technologies, to optimize water use and reduce wastage.		

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Adopt advanced rainwater harvesting systems for on-farm water collection, storage, and utilization during dry seasons.		
Introduce precision water management technologies, using sensors and smart irrigation systems to monitor soil moisture levels and automate irrigation schedules.		
Establish localized weather and hydrological forecasting systems, integrated with digital platforms, to provide real-time water availability and rainfall predictions.		
Promote the construction of community-scale water storage infrastructure, including farm ponds, reservoirs, and check dams, to enhance water security.		
Utilize GIS and remote sensing technologies for water resource mapping and planning, improving watershed management and flood control measures.		
Develop and promote desalination or water purification technologies, where appropriate, to improve water quality for agricultural use.		
Enhance drainage systems to prevent waterlogging and ensure proper water management in low-lying agricultural fields.		
Design and implement water reuse and recycling systems for agricultural purposes, including treated wastewater irrigation for non-edible crops.		
Promote mechanized water-lifting devices powered by renewable energy (e.g., solar water pumps) for sustainable water extraction.		

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Support the development of mobile applications and decision-support tools to provide farmers with water management guidance based on crop type, soil conditions, and climate data.		
Implement advanced water-efficient drinking systems such as automated waterers and nipple drinkers to minimise water wastage in livestock operations.		
Develop water harvesting systems tailored for livestock farms, including rainwater collection tanks and reservoirs, to ensure water availability during dry periods.		
Install solar-powered water pumps and distribution systems to provide a sustainable and reliable water supply for remote livestock operations.		
Introduce precision livestock water management technologies using smart sensors to monitor water consumption and detect leaks or malfunctions in watering systems.		
Construct water-retention structures such as small dams and infiltration ponds to recharge groundwater and store water for livestock during dry spells.		
Adopt permeable surfaces and drainage systems in livestock holding areas to reduce runoff and prevent water contamination.		
Implement temperature-regulating animal housing with innovative ventilation, misting, and cooling systems to reduce heat stress and conserve water.		
Utilize mobile water troughs and rotational water point systems to reduce overgrazing and improve access to water in large pastures.		
Develop livestock transport solutions with integrated water storage units to maintain hydration during long-distance movements.		

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Employ biofiltration and wetland systems for treating wastewater from livestock facilities, recycling it for safe reuse in non-drinking applications.		
Develop advanced marine and freshwater monitoring systems to track changes in fish populations, migration patterns, and habitat conditions driven by climate change.		
Create climate-resilient aquaculture systems using innovative water management and temperature regulation technologies to enhance sustainable fish production.		
Implement precision aquaculture technologies that incorporate satellite imaging, drones, and IoT sensors for real-time monitoring of water quality, fish health, and feed management.		
Introduce advanced fish tracking systems to study migration routes and breeding patterns, enabling better management of fish stocks and conservation efforts.		
Develop early warning systems for detecting temperature fluctuations, ocean acidification, and other marine ecosystem changes to protect fisheries from climate risks.		
Apply advanced coastal zone management techniques to prevent habitat destruction and erosion, safeguarding critical fish breeding and nursery grounds.		
Innovate fish processing and storage technologies to reduce post-harvest losses and improve the shelf life of fish products, enhancing food security and income for fishers.		

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Implement eco-friendly fishing gear technologies to minimise bycatch, reduce habitat destruction, and enhance sustainable fishing practices.		
Promote integrated water management systems for inland fisheries, combining rainwater harvesting, aquaculture ponds, and reservoir management for improved fish yields.		
Use automated feeding systems and water aeration technologies to optimise resource use and productivity in aquaculture operations.		
Policy/Institutional/Social Solutions		
Establish climate-smart water management training programs for farmers to enhance their capacity to adopt sustainable irrigation and water conservation techniques.		
Implement water resource insurance schemes to protect farmers from financial losses due to droughts, floods, and other water-related climate impacts.		
Develop mobile technology platforms to provide real-time water usage advisory services, including irrigation scheduling and water conservation tips.		
Create specialized water management extension services focused on sustainable irrigation, rainwater harvesting, and water reuse practices.		
Establish community-based water resource management committees to promote participatory decision-making and equitable water distribution.		
Develop policies to incentivize the adoption of water-efficient technologies, including tax breaks or subsidies for drip irrigation systems and rainwater harvesting infrastructure.		

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Create localized water resource monitoring and adaptation centers, offering tailored advice on drought management and flood risk mitigation.		
Promote public awareness campaigns on water conservation and sustainable usage practices tailored to the agricultural sector.		
Facilitate the formation of cooperative water user associations to manage shared water resources efficiently and resolve conflicts.		
Encourage investments in water-related research and innovation funds aimed at developing climate-resilient water management solutions.		
Integrate water resource management strategies into national and regional agricultural policies, ensuring holistic and cross-sectoral approaches to sustainable development.		
Promote access to improved water storage and distribution systems, ensuring year-round water availability for irrigation.		
Support community-driven water management plans that incorporate traditional knowledge alongside modern water conservation methods.		
Educate fishing communities on climate-smart fishing practices.		
Strengthen regulations against overfishing and illegal fishing practices.		
Establish community-based fisheries management programs to enhance local adaptive capacity.		
Develop alternative livelihood training programs for fishing communities facing resource challenges.		
Create digital platforms for real-time fisheries market information and climate alerts.		

Adaption Actions	Assessment of the impact of proposed actions	Supporting Policies/Laws
Create climate change adaptation training programs for fishing communities.		
Create insurance schemes for fishers against climate-related economic losses.		
Develop integrated coastal zone management plans addressing climate adaptation.		

7. Adaptation Action Plan for the Water Sector

7.1. Adaptation Action Plan for the Water Sector

Water sufficiency and quality are critical to national development, especially in Ghana, where the economy is an agrarian system with the majority of the labour force involved in agricultural and agricultural-related sectors. The importance of water for domestic, industrial and agriculture cannot be overemphasized. Climate change threatens the quantity and distribution of freshwater globally, especially in the tropics, where climate models have projected erratic rainfall patterns and increasing temperatures.

Adaptations actions to address water challenges in the face of climate change could be categorized under; nature-based solutions focusing on healthy and resilient functioning water and ecosystem through actions like wetland conservation, watershed management and buffer zones restoration; comprehensive river system planning for a robust flood risk management and monitoring system through actions such as real-time monitoring and forecasting of flows and climate-smart river management system; development of more resilient infrastructure; protection for critical infrastructure and vulnerable settlements; increased early warning, response and recovery systems focused on reducing vulnerability to disasters by implementing actions like installation of advanced weather instrument for prediction of extreme rainfall events and implementing a comprehensive disaster management plan; improved urban rainwater harvesting to reduce vulnerability to urban flood disasters and increased water availability for domestic use; increased accessibility to clean and safe water by ensuring proper monitoring, planning and supply of drinking water; implementation of climate-resilient irrigation infrastructure; and ensuring sustainable water supply or availability of hydropower generation.

Implementation of any of the adaptation actions for the water sector requires collaboration with at least one other sector to ensure sustainability. For instance, all irrigation projects requires the active participation of MoFA for effective implementation and adoption by farmers in Ghana.

Table 10: Adaptation actions for the water sector

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Restoration and conservation of wetlands	Improve the capacity of nature or vegetation to reduce or prevent erosion and fast runoff, increase infiltration, groundwater recharge, and water buffering.	Assessment of wetlands the development and implementation of intervention measures. Implementation of Ecosystem-based Adaptation.	Number of Wetlands and watersheds assessed and managed.	Short - term	Human Finance	WRC	EPA MEST MoLNR IWMI NGOs MoFA	
		Sustainable management of wetlands. Deployed automatic infiltration, erosion and water buffer monitoring systems.	Number of Wetlands and watersheds assessed and managed.	Mid-term	Human Finance			
Restoration of buffer zones	Improve the capacity of nature or vegetation to reduce or prevent erosion and fast runoff	Reduce the diversion of surface water for galamsey	Number of rivers without galamsey activities	Short - term	Human Finance	FC	WRC EPA MEST MoLNR IWMI NGOs MoFA	
		Stop galamsey on major river channels	Number of rivers without galamsey activities	Mid-term	Human Finance			

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Watershed management	Improve the capacity of nature or vegetation to reduce or prevent erosion and fast runoff, increase infiltration, groundwater recharge, and water buffering.	Comprehensive assessment and monitoring of water resources with a detailed geospatial database. Restoration of degraded water sources.	Produce a comprehensive water resources assessment and monitoring plan.	Short - term	Human Finance Technology	WRC	CSIR-WRI HSD EPA MEST NGOs	
		Effective implementation of water legislation and IWRM. Conduct watershed modelling.	Produce a comprehensive water resources assessment and monitoring plan.	Mid-term				
Promotion of Indigenous knowledge and practices in water conservation	To increase involvement of local knowledge in water conservation	Co-creation of watersheds, wetlands, and water conservation knowledge with the local or traditional people.	Number of Community awareness on IWRM	Short - term	Human Finance Technology	WRC	CSIR-WRI HSD EPA MEST NGOs IWMI	
		Integration of existing watershed Management Interventions into Local Area Plans and Implementation	Number of water legislations conducted.	Mid-term				
Strengthen research on water resource management including groundwater resources	Increase the number of research on water resources and build the capacity of researchers	Research on water resource management including groundwater resources and soil moisture Improve hydrological and groundwater modelling.	Number of studies on groundwater resources conducted.	Short - term	Human Finance Technology	CSIR-WRI	WRC HSD EPA MEST NGOs IWMI	
		Develop and initiate sustainable withdrawal of groundwater based on findings.	Real-time information on soil moisture and groundwater recharge.	Mid-term				

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Management plans for River basins	To improve flood risk preparedness and response by prevention.	Establish basin flood risk management plans. Conduct feasibility studies to build emergency storage, bypasses and controlled releases from heavy storms.	Number of feasibility studies conducted to build emergency storage, bypasses and controlled releases from heavy storms.	Short - term	Human Finance Technology	WRC	CSIR-WRI HSD EPA MEST NGOs IWMI	
		Build emergency storage, bypasses and controlled releases from heavy storms. Monitoring and evaluation of the river basin management	Number of river basin management plans prepared and implemented	Mid-term				
Real-time monitoring and forecasting of the flows.	To develop a robust flood risk management and monitoring system	Expand and improve hdrometeorological stations to include tributaries. Efficient database and information dissemination system on hydrometeorology.	Number of new and improved hydrometeorological stations established.	Short - term	Human Finance Technology	HSD	GMet WRC CSIR-WRI EPA MEST NGOs IWMI	
		State-of-art river monitoring and forecasting with decision support systems.	A functional flood forecast decision support system	Mid-term				

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Climate-smart River management system.	To develop a robust climate-smart management and monitoring system	Improve daily, seasonal and annual weather forecasts to generate hydrological flow forecasts. Enhance hydrological modelling and simulation for water resource forecasting.	A number of new and improved meteorological stations were established.	Short - term	Human Finance Technology	GMet	WRC HSD CSIR-WRI EPA MEST NGOs IWMI	
		State-of-art river monitoring and forecasting with decision support systems.	Number of forecasting products with decision support systems.	Mid-term				
Provide climate resilient infrastructure in critical areas for disaster risk reduction.	To enhance protection for infrastructures and settlements in vulnerable locations	Develop flood and stormwater management plans. Review the design of flood protection management protective structures like dams and drainage systems in flood-prone areas. With strict rules and regulations, the implementation of no-build zones on wetlands and flood drain zones can be strengthened.	Number of cities with flood and stormwater management plans developed and implemented.	Short - term	Human Finance Technology	NADMO	EPA HSD WRC CSIR-WRI MEST NGOs	
		Implementation of the climate resilient infrastructures, recommended in the flood and stormwater management plans.	Monitoring report on climate-resilient infrastructures.	Mid-term				

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Strengthen capacity in designing and developing climate resilient infrastructure.	Develop and promote resilient infrastructure	Develop climate resilient infrastructure guidelines and master plan. Ensure operation and maintenance of fast response and recovery infrastructure.	Climate resilient infrastructure guideline developed and implemented	Short - term	Human Finance Technology	MEST	EPA HSD WRC CSIR-WRI NGOs	
		Climate-resilient Infrastructure development.	Number of climate-resilient infrastructures designed and developed.	Mid-term				
Monitoring of extreme rainfall events that could cause flood	To improve early warning, response and recovery systems and capacity	Expand and improve existing early warning systems for extreme weather events and other hazards.	Number of installed or upscaled early warning systems.	Short - term	Human Finance Technology	GMet	HSD CSIR-WRI WRC EPA MEST NGOs IWMI	
		Flood modelling and forecasting. Strengthen extreme weather assessment and modelling studies.	Number of publications on extreme weather events and other hazards	Mid-term				
Comprehensive Disaster Management (DM) Plans	To reduce vulnerability to disasters	Review and update DM plans Implement programs and activities under the DM plan	Some DM plans were reviewed and implemented.	Mid-term	Human Finance	NADMO	CSIR-WRI EPA HSD MEST	

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Improved flood forecasting, preparedness and response system.	To enhance preparedness for disaster response	Modelling and forecasting of extreme weather events and dissemination of information. Installation of additional early warning systems in critical areas. Mapping flood-prone areas with specific, action-oriented communication before, during and after the flood events.	Number of floods forecasting products and services.	Short - term	Human Finance Technology	NADMO	HSD GMet CSIR-WRI WRC EPA MEST NGOs IWMI	
		Enhance flood forecasting and hazard and risk mapping.	Number of events-based maps produced.	Mid-term				
Enhance awareness of communities on water-related hazards	To improve knowledge on disaster risk management	Conduct awareness programs on water-related hazards at the community level Ensure operation and maintenance of fast recovery infrastructure.	Number of awareness of water-related disasters conducted .	Short - term	Human Finance	NADMO	CSIR-WRI WRC EPA MEST NGOs	
		Assessment of community Knowledge level towards flood and water-related disasters.	Number of water-related disasters Knowledge transferred programs conducted	Mid-term				
Harvesting rainwater for domestic	To reduce urban runoff	Exploring the volume of rainwater generated in water-stressed areas for domestic use. Developing assessment guide for integration of holistic use of water resources.	Report on rainwater volumes in water-stressed locations	Short - term	Human Finance Technology	WRC	GMet CSIR-WRI HSD EPA MEST IWMI NGOs	
		Integration of rainwater Harvesting structures into buildings and other amenities.	Assessment guide for integration of holistic use of water resources developed.	Mid-term				

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Adoption of Green roofing in cities	To reduce urban runoff	Develop a Green roofing framework and field guide for implementation in selected cities.	Number of green roof schemes (houses and cities) developed and implemented	Short - term	Human Finance	EPA	WRC CSIR-WRI HSD MEST NGOs	
		Review the Green roofing framework and field guide for upscaling or expansion to other cities	Framework for green roofing developed	Mid-term				
Ensuring proper monitoring, planning and supply of drinking water.	To enhance safe drinking water under climate change	Assessing the efficiency of existing water treatment facilities and water supply network systems. Explore alternative water supply technologies. Expand the implementation of Water Safety Plans WSPs) and proper water supply systems with adequate design.	Number of households/ Institutions with safe drinking water. Water supply duration and quality improved. Number of WSPs strengthened and implemented.	Short - term	Human Finance Technology	GWCL	GSB WRC MEST MoWHs CSIR-WRI	
		Explore and improve water treatment and supply network systems with proper management mechanisms. Explore and build additional storage facilities.	The number of treatment plants expanded. Number of additional storage facilities constucted	Mid-term				
Strengthen drinking water quality monitoring and surveillance.	To ensure safe drinking water	Strengthening laboratory services to test and monitor water quality.	Number of additional water quality parameters included in the monitoring. Integrated water quality and monitoring system established.	Short - term	Human Finance Technology	GWCL	GSB WRC MEST MoWHs CSIR-WRI	
		Strengthening water quality and monitoring information systems.	ISO certification ascertained.	Mid-term				

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
Strengthen database/ invention on drinking water supply schemes.	To provide real-time updates on water status	Establishment of a real-time water supply monitoring system.	Number of installed real-time water supply monitoring system	Short-term	Human Finance Technology	GWCL	GSB WRC MEST MoWHs CSIR-WRI	
		Establishment of a real-time water supply monitoring system.		Mid-term				
Improve planning, designing and implementation of climate-resilient irrigation infrastructures and systems.	Enhance water use efficiency and promote sustainable water management for irrigation	Rehabilitation of the traditional irrigation system to reduce water loss through climate proof structures integration. Promote adoption of micro irrigation (drip, sprinkler) by increasing accessibility to farmers through simple, affordable and smart technology. Climate proofing of the irrigation facilities. Ensure operation and maintenance of fast recovery infrastructure	Number of irrigation systems (under GIDA) rehabilitated. Number of open water harvesting structures constructed. Number of households adopting micro-irrigation systems.	Short-term	Human Finance Technology	GIDA	WRC MoFA EPA CSIR-WRI	

Adaptation Actions	Objectives	Action steps	Indicators of Success	Time frame	Resources	Lead	Implementing partners	Estimated cost
		Exploring alternative means of irrigation (lift irrigation). Promote adoption of micro-irrigation (drip, sprinkler) by increasing accessibility to farmers through simple, affordable and smart technology. Introduce and promote automated irrigation system for alternate wetting and drying (AWD). Explore tail water management and usage.	Number of climate proof irrigation schemes developed Total area cultivated under AWD Number of solar irrigation system initiated. Length of drainage system constructed for tail water management.	Mid-term	Human Finance Technology	GIDA	WRC MoFA EPA CSIR-WRI	
Incorporate resilience and watershed management plans while designing hydropower plants.	Increased resilience of hydropower infrastructures and/or technologies to climate change	Implementation of watershed management plans including check dams at appropriate locations (sedimentation control facilities). Develop inundation mapping of all the vulnerable communities of hydropower dams based on the flood discharge released from dams.	Number of watersheds management activities with areas. Number of inundation maps produced.	Short-term	Human Finance Technology	EPA	HSD EPA MEST	
		Monitoring and evaluation of watershed management plans.		Mid-term				

8. Policy and Institutional Framework for the Water Sector

8.1. Policy Framework for the Water Sector

In the legal context, water governance issues are handled by various institutions created by Acts of Parliament, as detailed in Table 11. Their water-related mandates, objects and/or functions are also shown. Under customary law, water is considered a common good and vested in stools, communities, and families, and this does not create private ownership over such a resource (Ofori Boateng, 1977). Rules evolved under customary law, governing domestic uses, animal watering, and fishing. This leads to certain management choices, such as determining whether an upstream or downstream part of a river could be used for drinking, washing, and animal watering. Fishing days are also determined and some riverine forest are also protected from encroachment. The sacredness of water and its customary use are also shrouded in religious beliefs.

The Water Resources Commission (WRC) is the umbrella institution mandated to regulate all water issues, particularly water withdrawal issues since all water is considered vested in the state. Some of the institutions include the Ghana Meteorological Services (GMet), Ghana Water Company Limited (GWCL), Ghana Irrigation Development Authority (GIDA), Environmental Protection Agency (EPA), Community Water and Sanitation Agency (CWSA), Volta Lake Transport Company (VLTC), Volta River Authority, Bui Power Authority, Public Utilities Regulatory Commission (PURC). The Ghana Standards Authority (GSA) ensures high quality of goods imported and exported and promotes standardisation in industry and commerce, including the water industry. The Food and Drugs Authority (FDA) operates in the context of public health and enforces standards for the sale of food, herbal medicinal products, cosmetics, drugs, medical devices, and household chemical substances. Food here implies food, beverages and drinking water.

According to Ministry of Water Resources, Works and Housing, Ghana (MWRWH) (2007), the Hydrological Services Department (HSD) of the Ministry of Water Resources, Works and Housing, the Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR), and the Ghana Meteorological Agency (GMet) constitute what is referred to as the Water Resources Information Services (WRIS) institutions. They provide data and other water resources-related information and services to support planning and decision-making. The universities also provide training and undertake water research. The work of the Forestry Commission (1999, Act 571) and Minerals Commission (1993, Act 450) have a lot of bearing on the conservation and utilization of water resources in Ghana. The interdependence of water and forestry in terms of water conservation is well-known, requiring the maintenance of tree cover, particularly at the sources of streams and rivers.

Table 11: Water sector institutions, their legislative frameworks and water-related mandate, object and/or functions

Water Sector Institution	Legislative Framework	Water-related mandate, object and/or functions
Water Resources Commission	1996, Act 522 2001, LI 1692	(a) Propose integrated water resources management plans to guide the utilization, conservation, development and improvement of water resources; (b) initiate, control and co-ordinate activities connected with the development and utilization of water resources; (c) grant water rights; (d) Collect, collate, © store and disseminate data or information on water resources; (f) engage water sector agencies to undertake scientific investigations, experiments or research into water resources (g) monitor and evaluate programmes for the operation and maintenance of water resources; (h) advise the Government on any matter likely to have adverse effect on the water resources; (i) advise pollution control agencies in Ghana on matters concerning the management and control of pollution of water resources; and (j) perform such other functions as are incidental to the foregoing.
Volta River Authority	1961, Act 46 1962, Act 95	(a) Generation of electrical power for general industrial, commercial and domestic uses by the means determined by the Authority, and in particular in the first instance, by the construction and operation of a dam and hydro-electric generating station in the vicinity of Akosombo; (b) supply of electrical power generated by the Authority to distribution companies, bulk customers, the township of Akosombo and Kpong, and any other consumer in Ghana or elsewhere under an arrangement agreed upon between the Government and the Authority; (c) the provision, when and so far as practical, of facilities and assistance for the development of the lake as a source of fish, and as a route for the transportation of goods and passengers, and in any other manner, and (d) the development of the lakeside area for the health and wellbeing of the inhabitants, and people living adjacent to that area.
Volta Lake Transport	1961, Act 46 1974, LI 862	Provision of lake transport services for both passengers and bulk goods for the North/South operations and cross lake ferry operations
Public Utilities Regulatory Commission	1997, Act 538 2010, Act 800	Regulation of the standard of water services including the quality of drinking water provided by the Ghana Water Company Limited and also the tariff set by the company for urban water supply
Hydrological Services Department	No legal framework	Programming and co-ordination of coastal protection works, construction and maintenance of storm drains countrywide and the monitoring and evaluation of surface water bodies in respect of floods.
Ghana Water and Sewerage Corporation Ghana Water Company Limited	1965, Act 310 1993, Act 461 1999, LI 1648	(a)Abstraction, treatment and supply of potable water to urban communities; (b) planning and development of water supply systems in urban communities in Ghana; (c) conduct research and engineering surveys relative to water and related subjects; (d) contracting out the design, construction, rehabilitation and expansion of existing as well as new water supply infrastructure; (c) provision of quality service delivery to consumers in respect of quantity and quality of water supplied; (f) periodic submission of proposals to the Public Utility Regulatory Commission for tariff review

Water Sector Institution	Legislative Framework	Water-related mandate, object and/or functions
Ghana Meteorological Agency	2004, Act 682 2019, Act 1002	Provide meteorological services in the country and ensure the operation and maintenance of international standards and practices in meteorology in the country.
Ghana Irrigation Development Authority	1977, SMCD 85	(a) Formulate plans for the development of irrigation; (b) develop the water resources of the country for irrigated farming, livestock improvement and fish culture; (c) execute comprehensive programmes for the effective use of irrigated lands in co-operation with any other agencies involved in providing extension services to farmers; (d) carry out land-use planning in areas earmarked for development in order to conserve the soil and water resources in those areas; (c) lay out the environs of each project area for housing purposes and for the provision of any other social amenities; (f) co-operate with any other agencies for safeguarding the health and safety of the population living within and around irrigation project areas; (g) undertake any other activities that are incidental or conductive to the performance of its functions under this Act.
Environmental Protection Council **Environmental Protection Agency** **Environmental Protection Authority**	1974, NRCD 23a 1976 SMCD 58 1994, Act 490 2025, Act 2114	(a)Advise the minister on the formulation of policies on all aspects of the environment and in particular to make recommendations for the protection of the environment; (b) coordinate activities of bodies concerned with the technical and practical aspects of the environment and serve as a channel of communication between such bodies and the ministry; (c) coordinate activities of such bodies as it considers appropriate for controlling the generation, treatment, storage, transportation, and disposal of waste. The new Environmental Protection Act, 2025 (Act 1124) serves EPA the primary legislation for: (1) Environmental Protection, (2) Pesticides Control and Management, (3) Control and Management of Hazardous Wastes and Other Wastes, (4) Control and Management of Electrical and Electronic Waste, and (5) Coordination of Climate Change Responses
Community Water and Sanitation Agency	1998, Act 564	Facilitate the provision of safe water and related sanitation services to rural communities and small towns.
Water Research Institute of the Council for Scientific and Industrial Research	1996, Act 521	Undertake research into all aspects of water resources (both living and non-living) of Ghana in order to provide scientific and technical information and services needed for sustainable development, utilisation and management of the resources for socioeconomic advancement of the country.

Water Sector Institution	Legislative Framework	Water-related mandate, object and/or functions
Bui Power Authority	2007, Act 740 2020, Act 1046	(a) Generate electrical power for general industrial and domestic use, and the operation of the dam and the hydroelectric generating station in the vicinity of Bui; (b) Construct a transmission system for the evacuation of the electrical power generated at the dam to the national electricity grid; (c) Supply the electrical power generated at the dam to a public utility licensed under the Energy Commission Act, 1997 (Act 541) responsible for the transmission or distribution of electrical power to the public, the township of Bui and its environs, and any other consumer in Ghana or elsewhere under an arrangement agreed on between the Government, the Authority, a consumer and the Electricity Company of Ghana or any other public utility licensed under the Energy Commission Act 997 (Act 541); (d) Provide facilities and assistance for the use of the lake so created by the construction of the dam for multipurpose uses.
Ghana Standards Authority	1973, NRCD 173	(a) Establish and promulgate standards with the object of ensuring high quality of goods, produced in Ghana, whether for local consumption or for export; (b)Promote standardisation in industry and commerce;
Food and Drugs Authority	1992, PNDCL 305b 2012, Act 851	Provide and enforce standards for the sale of food, herbal medicinal products, cosmetics, drugs, medical devices and household chemical substances.

Source: Compiled by Authors from the gazetted laws on the establishment of the institutions

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8.1.1. Climate-related policy issues on water

Ghana's climate-related policy issues on water works on the principle of recognizing water as a common good, ensuring adequate mitigating strategies are put in place in support of vulnerable groups, and minimizing effects of climate variability and change in the context of adequate land use planning and enforcement in respect of waterways and flood-prone areas. Details on the principles, challenges, policy objectives, and actions are below (Ministry of Water Resources, Works and Housing, Ghana (MWRWH), 2007).

"Principles

(i). Recognize water as a finite and vulnerable resource, given its multiple uses;

(ii). (Coordinate water resources planning with land use planning; and

(iii). Adopt the river basin (or sub-basin) as a planning unit;

Challenges

(i). Ensure adequate response strategies are in place; and

(ii). Ensure adequate support to vulnerable people for implementing their own coping strategies.

Policy objectives

(i). Minimize the effects of climate variability and change; and

(ii). Institute measures to mitigate the effects of, and prevent damage caused by extreme hydrological occurrences (floods and droughts).

Policy measures and/or actions

(i). Construct flood protection structures at appropriate locations;

(ii). Apply appropriate technologies to provide the necessary information for detection and early warning systems for floods and drought;

(iii). Establish and enforce appropriate buffer zones along river banks, including measures to compensate for loss of lands;

(iv). Ensure that land-use planning/building regulations are adequate and enforced in respect of waterways and flood-prone areas;

(v). Provide water conservation structures of adequate capacity after carrying out environmental assessments considering multiple uses (e.g., fisheries and tourism) and removing conflicts (e.g., fencing of intakes in dams to allow for restricted fishing);

(vi). Ensure rainwater harvesting techniques are incorporated into the building code and enforced; and (vii) Ensure implementation of mitigation strategies in consultation with affected communities.

8.2. Institutional Arrangements for the Implementation of the Sectoral Plan

Table 12 present a range of institutions with roles for the implementing the Adaptation Action Plan for the Water Sector.

Table 12: Institutional Arrangement for the Water Sector Plan

	Government Ministries and Agencies	
SN	**Name of institution**	**Mandate**
1	**Ministry of Environment, Science, Technology, and Innovation (MESTI)**	*Leads and coordinates the NAP process, ensuring that climate change adaptation strategies are integrated into the agricultural sector's policies and development plans.* *Collaborates with key stakeholders to provide technical support for climate resilience.* *Responsible for monitoring and evaluating the implementation of adaptation actions in the agricultural sector, ensuring that progress is tracked and resources are effectively allocated.* *Leads in formulating climate and environmental policies and programs.* *Hosts the national climate change committee to oversee the implementation of the Innovation national climate change policy.* *Coordinates the regular preparation and implementation of the Nationally Determined Contribution.*
2	**Environmental Protection Agency (EPA)**	*Implementing entity of the NAP project, funded by the Green Climate Fund (GCF).* *Provides technical expertise and guidance on environmental impact assessments, ensuring that agricultural practices are climate-resilient and environmentally sustainable.*
3	**Water Resources Commission (WRC)**	*To regulate and manage the utilization of water resources, including coordinating relevant government policies related to water management.* *Overseeing the sustainable use and protection of water sources within a designated area by issuing permits, developing conservation plans, and monitoring water quality.* *Developing strategies for water resource development and management, including identifying potential water sources and managing water scarcity issues.* *Implementing measures to prevent and mitigate water pollution.*
4	**Hydrological Service Department (HSD)**	*Responsible for the planning, design, execution, operation, and maintenance of flood control mechanisms, coastal engineering works, drainage improvement works, and operational and applied hydrology in the country.* *Programming and coordinating coastal protection works; constructing and maintaining storm drains countrywide; and monitoring and evaluating surface water bodies regarding floods.*
5	**CSIR- Water Research Institute (WRI)**	Research all aspects of water resources, including living and non-living resources, for the socioeconomic advancement of the country Provide scientific and technical information and services Develop strategies for the sustainable development, utilization, and management of water resources

6	**Ministry of Lands and Natural Resources (MLNR)**	*Collaborates with other relevant ministries, agencies, and stakeholders, such as MESTI, MoFA, the EPA, the private sector, civil society, and local communities, to ensure the effective coordination and integration of the NAP for the agricultural sector.* *Provides leadership and guidance in the management of land, forest, wildlife, and mineral resources, which are essential for the resilience and productivity of the agricultural sector.* *Ensures sustainable and equitable land delivery services, which facilitates the access and tenure security of farmers, especially women and vulnerable groups.*
7	**Ministry of Finance (MoF)**	*Facilitate the domestication of the SDGs in the country.* *Prepares SDG-compliant budget including climate change.* *Tracks domestic and international climate change inflows.* *Serves as the national designated entity for the Green Climate Fund.*
8	**Ministry of Local Government and Rural Development (MLGRD)**	*Responsible for supporting the Metropolitan, Municipal, and District Assemblies (MMDAs) to integrate climate change adaptation into their local planning and budgeting processes and to access and manage climate finance.* *Enhances the capacity and coordination of the MMDAs and other local stakeholders, such as traditional authorities, civil society organizations, and community groups, to implement and monitor adaptation actions.* *Facilitates the participation and empowerment of the local population, especially women, youth, and vulnerable groups, in the identification and prioritization of their adaptation needs and solutions.* *Strengthens the linkages and synergies between the national and local levels of governance and fosters multi-sectoral and multi-level collaboration on climate change adaptation.*
9	**Ministry of Fisheries and Aquaculture Development (MoFAD)**	*Ensures the sustainable management and development of fisheries resources.* *Supports the growth of aquaculture to improve fish production and food security.* *Enforces laws and policies to combat illegal, unreported, and unregulated fishing practices.* *Provides training and resources to stakeholders to improve livelihoods in the fisheries sector.*

10	**Ministry of Water Resources and Sanitation (MWRS)**	*Ensures sustainable use and management of water resources for agriculture.* *Facilitates the development and maintenance of irrigation infrastructure.* *Promotes sanitation practices to safeguard water quality for agricultural use.* *Develops and enforces policies for equitable water access and conservation.*
11	**Ministry of Trade and Industry (MoTI)**	*Supports the establishment and growth of agro-industries.* *Facilitates access to domestic and international markets for agricultural products.* *Promotes value addition to raw agricultural produce for economic growth.* *Develops and enforces trade policies to enhance competitiveness in the agricultural sector.*
12	**Ministry of Gender, Children, and Social Protection (MoGCSP)**	*Aligns agricultural policies with the unique needs and priorities of men and women farmers.* *Addresses gender disparities in access to climate information, financial resources, and agricultural inputs under the NAP.* *Provides training and support tailored to enhance the resilience of women farmers to climate impacts as outlined in the NAP.* *Includes targeted interventions in the NAP to safeguard vulnerable groups, particularly women and children, against climate risks.*
13	**Ministry of Energy**	*Incorporates renewable energy solutions into the NAP to support agricultural adaptation in rural areas.* *Develops energy-efficient irrigation technologies to enhance climate resilience in farming under the NAP.* *Expands energy access for smallholder farmers to improve productivity and resilience to climate change.* *Facilitates the integration of clean energy technologies in agricultural practices as part of the NAP.*
14	**Ministry of Health**	*Supports the NAP by strengthening health systems to respond to climate-induced health risks in farming communities.* *Implements programs to reduce climate-related diseases that affect farmers, such as heat stress and waterborne diseases, within the NAP framework.* *Ensures that the NAP includes strategies for improving the nutrition and health of agricultural communities affected by climate change.* *Incorporates climate health education into the NAP to increase awareness of health risks linked to climate impacts on agriculture.*
15	**Department of Gender (DoG) under the Ministry of Gender, Children, and Social Protection (MoGCSP)**	*Ensure that the NAP is gender-responsive and addresses the different needs, capacities, and priorities of men and women farmers* *Works in collaboration with other ministries, departments, and agencies, such as MESTI, MoFA, the EPA, and the Department of Climate Change, to ensure the effective integration and coordination of gender and climate change adaptation in the agricultural sector*

16	**National Development and Planning Commission (NDPC)**	*Ensures the integration of climate change issues into national development policy, planning, and budgeting processes.* • Coordinates the preparation of sectoral and national annual progress reports, which also cover climate change issues. *Provides strategic direction and oversight for integrating climate change adaptation into the national, sectoral, and sub-national development plans and policies.* *Mobilizes and allocates resources for implementing, monitoring, and evaluating the NAP and its related programs and projects.* *Facilitates the alignment of the NAP with the Sustainable Development Goals (SDGs), the African Union Agenda 2063, and other relevant regional and international frameworks.*
17	**Ghana Meteorological Agency (GMet)**	*Collaborates with other relevant institutions, such as MESTI, MoFA, the EPA, and the NDPC, to ensure the coordination and integration of weather and climate services into the NAP process.* *Enhances the capacity and awareness of the agricultural sector and the general public on the use and application of weather and climate services for adaptation decision-making.*
	Non-governmental organizations (NGOs) and Civil Society Organizations (CSOs)	

	Name of institutions	Mandate
1	**CARE International**	Supports the implementation of the NAP project and promotes gender-responsive and ecosystem-based adaptation approaches.
2	**Oxfam**	Implements community-based adaptation projects and influences national and international policies on climate change adaptation.
3	**Environmental Protection Association of Ghana (EPAG)**	Engages in advocacy, education, and research on environmental and climate change issues.
4	**Ghana Civil Society Platform on Sustainable Development Goals (SDGs)**	Coordinates the efforts of various CSOs to monitor and report on the progress of the SDGs, including the climate action goal.

8.3. Gender Consideration for the Water Sector Adaptation Plan

Addressing the gendered impacts of climate change on water security requires a multi-scalar, intersectional approach that considers the diverse experiences and needs of different groups. Policies and programs must be designed to enhance the adaptive capacity of women and vulnerable groups by ensuring equitable access to resources, information, and decision-making processes. For instance, integrating gender perspectives into water management policies can help address the specific needs of women and marginalized groups. This includes providing women with access to training and resources for sustainable water management practices and involving them in decision-making processes at all levels. Additionally, policies should aim to reduce the burden of water collection on women by improving infrastructure and ensuring reliable and safe water supplies (Sultana, 2018).

Efforts to enhance gender equality in the context of climate change can also benefit from the insights of feminist political ecology, which emphasises the importance of understanding gender-environment relations as dynamic and context-specific. This perspective highlights the need to move beyond simplistic narratives that portray women solely as victims or saviours and instead recognize the complex and varied ways in which gendered identities and power relations shape responses to climate change (Sultana, 2018).

8.4. Funding Arrangements for the Sector Plan

Successfully implementing the actions outlined in this sector plan will require significant financial investment from sector ministries, departments, and agencies. To facilitate this, it is essential that these institutions incorporate the plan into their annual institutional budgets and work plans, ensuring that the Government of Ghana allocates adequate resources.

In addition to government funding, securing financial support from international donors, development partners, and private sector stakeholders is crucial. These partnerships will provide the necessary financial backing to complement domestic resources. Furthermore, institutions should consider innovative financing options such as public-private partnerships (PPPs), climate adaptation funds, and green bonds to strengthen financial resilience and support long-term sustainability.

Regular monitoring and reporting of financial allocations and expenditures will be essential to ensure effective and transparent use of resources. This will promote accountability and stakeholder confidence, creating an environment conducive to continued investment in the water sector's adaptation and resilience efforts.

8.5. Anticipated Implementation Challenges and Proposed Solutions

8.5.1. Financial and Logistical Support

Overcoming financial and logistical barriers is crucial to effectively implementing national programs and initiatives. Solely relying on external donor funding for these essential projects is not sustainable, as it often leads to project delays or incomplete execution. To ensure the success of this action plan, the Government of Ghana should prioritise the inclusion of dedicated budget allocations for its implementation within the national fiscal framework.

Additionally, ministries, departments, and agencies must explore innovative domestic funding mechanisms, such as implementing resource usage fees and environmental taxes and engaging in public-private partnerships (PPPs). These efforts will strengthen national ownership of the plan and reduce dependency on external resources.

In parallel with these domestic measures, the government should actively pursue financial support from international climate funding mechanisms and regional development programs to supplement national efforts. By diversifying funding sources and streamlining financial coordination, Ghana can ensure that its action plan is fully financed and can be executed effectively.

8.5.2. Capacity Building

The successful execution of the action plan is often hindered by gaps in technical expertise, insufficient human resource capacity, and a lack of institutional knowledge, particularly at regional and district levels. To address these gaps, priority should be given to strengthening capacity through targeted training and development initiatives. These initiatives should equip local government personnel and community stakeholders with the necessary skills and knowledge to implement the plan effectively.

Capacity-building efforts could include tailored training programs, practical workshops, and access to relevant educational resources. Collaboration with universities, professional organisations, and international bodies can significantly enhance the quality and accessibility of these training opportunities. Additionally, mentorship schemes and knowledge exchange programs with seasoned institutions will facilitate the transfer of expertise and support the development of sustainable institutional capacity over time.

8.5.3. Government Commitments

Inconsistent governmental commitment, reflected in policy gaps, irregular resource allocation, and shifting priorities, often hampers the successful implementation of national action plans. To overcome this challenge, the Government of Ghana must demonstrate strong, continuous political will by integrating the action plan into the broader national development framework, ensuring it remains a priority through multiple electoral terms.

This requires establishing robust accountability mechanisms to monitor progress, ensuring consistent funding in annual budgets, and fostering effective coordination among ministries. Regular progress assessments, conducted at the highest government levels and followed by public updates, will help maintain focus and increase transparency, fostering stakeholder trust and engagement.

Collaboration with civil society organisations, development partners, and advocacy groups will play a critical role in maintaining momentum, ensuring that the government stays focused on implementing the plan. Furthermore, improving coordination among ministries and departments responsible for managing climate risks, especially water and agriculture-related ones, will be essential to effective and streamlined execution.

8.5.4. Weak Institutional Coordination

Ineffective coordination between institutions presents a significant obstacle to successfully implementing Ghana's national adaptation action plan. Overlapping responsibilities, ambiguous mandates, and lack of clear communication between ministries and agencies often result in inefficiencies and hinder collaboration. Furthermore, resource constraints in both human capacity and finances reduce the ability of these institutions to coordinate and execute adaptation strategies effectively. Inconsistent policies and fragmented regulations across different sectors further complicate the process.

To overcome these barriers, several measures must be adopted. First, delineating the roles and mandates of each institution will eliminate redundancy and streamline operations. Regular cross-institutional meetings and establishing effective communication platforms will promote seamless information exchange and collaborative action. Additionally, prioritising staff training and capacity-building efforts will enhance the institutions' operational effectiveness in implementing the adaptation plan. Securing sufficient funding and resources will also ensure these institutions can function fully. Lastly, harmonising policies and aligning regulations across sectors will foster a unified approach, enabling coordinated and impactful adaptation efforts.

8.6. Framework for Adaptation Monitoring and Evaluation

The National Development Planning Commission (NDPC) was established in 1994 by Act 479. By Act 480 in the same year, NDPC was given the responsibility as the national coordinating body of the Decentralised Development Planning

System in Ghana. NDPC provides the legal basis for monitoring and evaluation (M&E) in Ghana. In order to guarantee the successful implementation and evaluation of development plans, including policies for climate adaptation, this act requires the creation of strong M&E frameworks. The act places a strong emphasis on the value of openness and accountability in the formulation and implementation of national development programs. Ghana's National Adaptation Plan (NAP) for the water sector includes a framework for adaptation monitoring and evaluation (M&E) that is intended to monitor development, evaluate efficacy, and promote learning to improve climate resilience. The essential elements are:

Objectives of the M&E Framework

- **Track Progress:** *Keep an eye on how adaption measures are being carried out and compare results to predetermined goals and metrics.*
- **Evaluate Effectiveness:** *Determine how adaptation tactics affect the water sector's resilience and vulnerability levels.*
- **Facilitate Learning:** *Share knowledge and takeaways to help guide future adaption planning and execution.*

A. Key Components

- **Indicators and Metrics:** *To monitor adaptation efforts, create SMART (specific, measurable, achievable, relevant, and time-bound) indicators. These metrics ought to address a number of topics, including afforestation for buffer zones, water yields, early warning system platforms and frameworks, and water quality monitoring indicators.*
- **Data Collection and Management:** *Provide reliable procedures for gathering, organizing, and evaluating data. This involves gathering pertinent data through field surveys, instrumentations on river bodies and in major watersheds, and remote sensing.*
- **Baseline Assessments:** *Gather baseline data to assess the current state of the water sector and use the same data as a reference for evaluation.*
- **Regular Reporting:** *Establish a reporting schedule for adaptation actions and results on a regular basis. This guarantees accountability and openness throughout the adaptation process.*

B. Evaluation Processes

- **Periodic Evaluations:** *Conduct evaluations at strategic intervals to assess the effectiveness of adaptation measures. This includes mid-term reviews and end-of-project evaluations.*
- **Impact Assessments:** *Conduct impact assessments to ascertain the long-term effects of adaptation actions on water resource availability and accessibility and resilience of vulnerable communities to water disasters like floods.*
- **Stakeholder Feedback:** *Incorporate feedback from stakeholders, including households, major water industries, policymakers, and researchers, to refine and improve adaptation strategies.*

C. Learning and Improvement

- **Knowledge Sharing:** *Facilitate the sharing of knowledge and best practices among stakeholders through workshops, seminars, and publications.*
- **Adaptive Management:** *Make wise modifications to adaption plans using the knowledge gathered from M&E activities. This guarantees that the strategy will continue to adapt to shifting weather patterns and new difficulties.*

- **Capacity Building:** *Strengthen the capacity of institutions and individuals involved in the M&E process through training and technical support.*

D. Institutional Arrangements

- **Coordination Mechanism:** *To supervise the M&E process, set up a coordination system with key organizations including the Environmental Protection Authority (EPA), the Ministry of Environment, Science and Technology (MEST), and Water Resources Commission (WRC) and Council for Scientific and Industrial Research -Water Research Institute (CSIR-WRI).*

- **Roles and Responsibilities:** *Clearly define the roles and responsibilities of various stakeholders in the M&E framework to ensure effective implementation and accountability.*

By applying this complete M&E strategy, Ghana can ensure that its adaptation efforts in the water sector are effective, efficient, and continuously improving, hence boosting the resilience of its water infrastructure and riverine systems to climate change.

9. Conclusion and Way Forward

Addressing climatic hazards in the water sector requires a multifaceted approach that includes both structural and non-structural measures, with adequate financing being critical yet often overlooked. Integrated Water Resources Management (IWRM), land management, nature-based solutions, improved irrigation, and infrastructure enhancements are essential for building water security and resilience. Effective adaptation involves returning systems to their original state and adapting them to new resilient equilibria supported by strong institutional frameworks, capacity development, and technological innovation. Stakeholder engagement and a gender-sensitive approach ensure that adaptation strategies are inclusive and context-specific. Monitoring, evaluation, and learning (MEL) frameworks are crucial for assessing and adjusting adaptation measures, ensuring their sustainability. By integrating these strategies and securing proper funding, the water sector can effectively manage climate risks and contribute to sustainable development.

As a recommendation, increasing funding and investment through innovative financing and partnerships. Implementing Integrated Water Resources Management (IWRM) and enhancing land management practices are essential for sustainable water management. Adopting nature-based solutions, improving water use efficiency, advancing water recycling and reuse, and enhancing irrigation techniques will further support resilience. Strengthening water management infrastructure, promoting dryland agriculture, and expanding water storage and conservation techniques are vital. Additionally, sustainable groundwater extraction, reducing water leakage, and developing desalination projects are key. Engaging and educating communities, implementing robust monitoring and evaluation frameworks, and adopting a gender-sensitive approach will ensure effective and inclusive adaptation strategies. Strengthening institutional and governance frameworks is also necessary for successful planning and implementation

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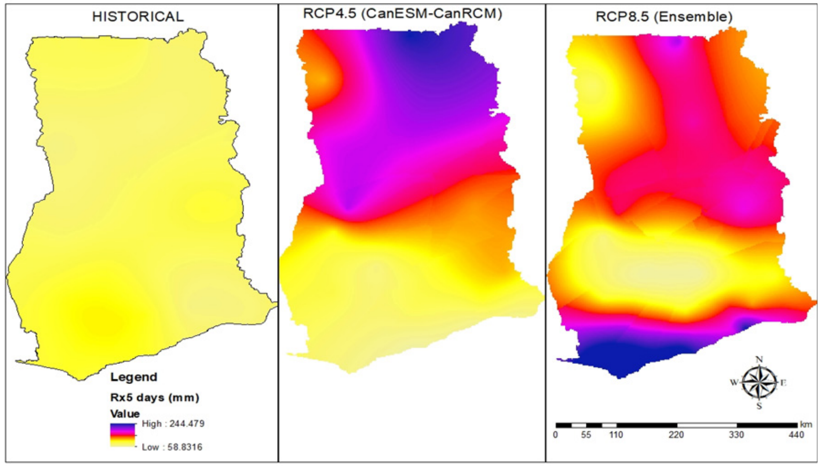
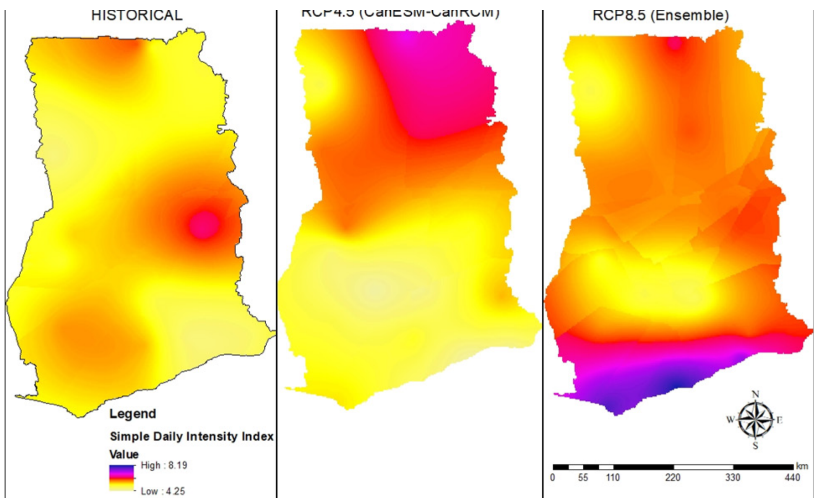
Appendix

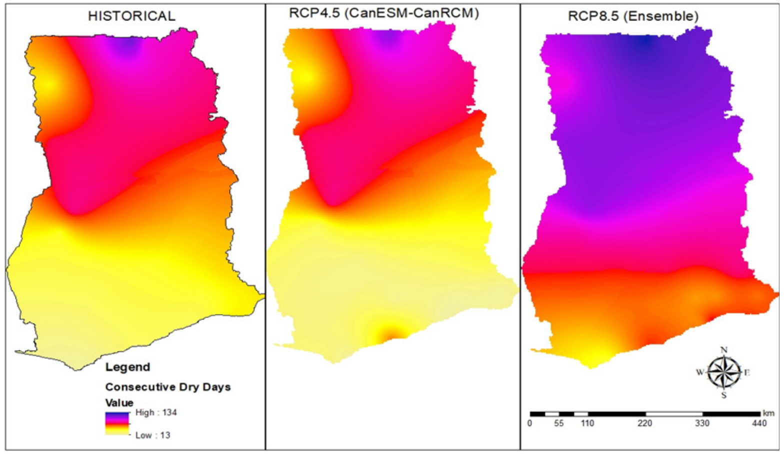
Appendix I: Rx5 days rainfall amount



Appendix II: Simple Daily Intensity Index (SDII)



Appendix III: CDD



Appendix IV: