Pre-feasibility Study

of Liberia Simplified Approval Process (SAP) Proposal submitted to Green Climate Fund (GCF)

Environmental Protection Agency, Liberia (April 2020)

Table of Contents

List of Figures

List of Tables

Acronyms

AfDB	African Development Bank
AOGCM	Atmosphere-Ocean Global Circulation Model
ASBU	Aviation System Block Upgrades
AWOS	Automated Weather Observing Systems
CCI	Commission for Climatology
CCM3	Community Climate Model version 3
CDD	Consecutive Dry Days
CMIP	Coupled Model Intercomparison Project
CMIP5	Coupled Model Intercomparison Project phase 5
CORDEX	Coordinated Regional Downscaling Experiment
COSMO	Consortium for Small-scale Modelling
COSMO-CLM	Consortium for Small-scale Modelling – Regional Climate Model
CSDI	Cold Spell Duration Indicator
CWD	Consecutive Wet Days
EEZ	Exclusive economic zone
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
ERA	European Centre for Medium-Range Weather Forecast Re-Analysis
ET-SCI	Expert Team on Sector-specific Climate Indices
EWS	Early Warning System
FDA	Forestry Development Authority
GANP	Global Air Navigation Plan
GCF	Green Climate Fund
GCM	Global Circulation Model
GDP	Gross Domestic Product
GERICS	Max Planck Institutes Climate Service Centre Germany
GFCS	Global Framework for Climate Services
GHG	Greenhouse Gas
GoL	Government of Liberia
GPCC	Global Precipitation Climatological Centre
ICAO	International Civil Aviation Organization
ITCZ	Inter-Tropical Convergence Zone
LCCTF	Liberian Climate Change Trust Fund
LICIAM	Liberia Climate Impact Assessment Model
LMHS	Liberia Meteorological and Hydrological Services
MoA	Ministry of Agriculture
MoLME	Ministry of Lands, Mines and Energy
MPI	Max Planck Institutes
MPI-ESM	Max Planck Institute – Earth System Model
NAP	National Adaptation Plan
NCCSC	National Climate Change Steering Committee
NCAR	National Center for Atmospheric Research
NDC	Nationally Determined Contribution

OPACE	Open Panel of CCl Experts
PAPD	Pro-Poor Agenda for Prosperity and Development
PESTLE	Political, economic, socio-cultural, technological, legal and environmental factors
PMO	Project Management Office
PSC	Project Steering Committee
RCA4	Rossby Centre regional atmospheric model version 4
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
REMO	Regional Climate Model
SMHI	Swedish Meteorological and Hydrological Institute
SPI	Standardized Precipitation Index
SWOT	Strengths, Weakness, Opportunities and Threats analysis
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
WAM	West African Monsoon
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organization
WSDI	Warm Spell Duration Indicator

1 Executive Summary

Climate change, recently referred to as Climate emergency by the Global Climate Fund (GCF), is recognised as one of the major challenges of the twenty-first century. Liberia's vulnerability to climate-related challenges is worsening over time, as temperatures increase, sea-levels rise, and extreme weather conditions such as floods and droughts persist as common phenomena. This feasibility study serves to augment the project proposal by the Environmental Protection Agency (EPA) of Liberia to the Green Climate Fund. The proposed project seeks to revitalise and build climate information services in the country. It assesses Liberia's climate information services regarding the historical underpinnings that characterise the present state. The potential impact of different response mechanisms to the climate hazards experienced in the country is evaluated with a focus on the resulting economic and social returns.

The objective of the project is to further strengthen Liberia's climate-related observing and monitoring capabilities, early warning systems and other environmental-related information by effecting a paradigm shift towards evidence-based informed climate decision-making, planning, and response actions. The overarching goal is to integrate green growth, environmental resilience and adaptation into national development planning[1] through effective climate information systems.

The project objectives respond to climate risks and hazards the affect key economic sectors of Liberia's economy such as agriculture, health, fisheries, forestry, water and sanitation, energy, among others. The attainment of the defined objectives will result in a robust climate information services in the country, accurate prediction and timely actions for climate aversion, a reduced loss across the different economic sectors, and an overall improvement in the quality of life of the citizenry.

The project will improve on the preceding initiatives to ensure effective generation and coordination of climate information and services to support informed decision-making processes in public and private sectors. Also, the project will sustainably transform the status quo of climate business in Liberia into a technologically driven end-to-end service delivery to private corporations, and potentially attract neighbouring countries interest in improving outcomes in climate-sensitive sectors.

[1] Pro-Poor Agenda for Prosperity and Development (PAPD), MFDP, Monrovia, Liberia (2018)

2 Background and Context

Liberia, located on the Atlantic Coast of West Africa along the Gulf of Guinea, and spanning an area of 38,000 square miles and 350 miles along the coastal belt, is at risk of an array of climate disasters. In the past, Liberia endured one of the longest political unrests in recent time when fourteen years of civil war ravaged the country, displaced millions, and interrupted economic activities.

Liberia endured over a decade of civil war that led to the loss of lives and destroyed infrastructure, including the country's hydromet stations. A total of 34 manual water-level stations and 64 rainfall stations existed before the war. However, there are currently only 15 water-level stations and 14 rainfall stations currently in operation. It has been the goal of the hydromet services to increase capacity to the pre-war level. This project will build on the progress made in the previous Early Warning System (EWS) projects to expand and revitalise climate information systems to deliver accurate, relevant, and timely climate services necessary to adapt to climate hazards.

The threats of climate change in Liberia presents a dire challenge that can potentially cause havoc and destroy many lives and property in its wake. Both researchers and policymakers recognised the hazards of climate change to countries such as Liberia, where the majority of the population depend on agriculture for their livelihood (Stanturf, 2013; USAID, 2012). Liberia's vulnerability to climate-related challenges is worsening over time, as temperatures increase, sea-levels rise, and extreme weather conditions such as floods and droughts persist as common phenomena. Recent climate change indicators in Liberia include severe flooding changes in rainfall patterns, and rising temperatures, which affects food security, health, education, and other economic sectors (Kenneh, 2016; Observer, 2018). These climate dynamics in Liberia pose greater threats to its already challenged economic sectors.

Most of the country's population, infrastructure, and key economic sectors are exposed to the dangers that economy climate change, coastal erosion, windstorm, flooding, among others. The fisheries sector is threatened as the ecosystems along the coastal belt are destroyed, and temperatures rise. Agriculture is the most exposed to the risks of climate change though it contributes the most in terms of employment and GDP. The Government of Liberia (GoL), in response to the burgeoning climate challenges, developed a National Policy and Response Strategy on Climate Change to streamline climate-change issues and prioritise mitigation strategies in its development planning processes (EPA, 2018). The Climate Change Strategy includes systems to monitor and detect changes that will affect agricultural production.

2.1 Baseline Assessment and Situational Analysis/SWOT

There are climate-centred state agencies and units within departments that focused on championing public understanding of climate change, as well as mitigation and adaptation strategies within the country. However, a recent Afrobarometer survey (Wongbe, 2018) indicates that more than half of Liberians have heard of climate change, with a majority reporting that climate change is making life worse in the country, while many are not aware of its causes. There is a knowledge gap in the country when it comes to climate risks, hazards, and associated vulnerabilities. This fact is further revealed in a survey conducted as part of the base assessment for this project. A recent survey of people in Liberia from different professions at ministries, departments and agencies revealed a significant understanding of climate change variability (see Figure 1).

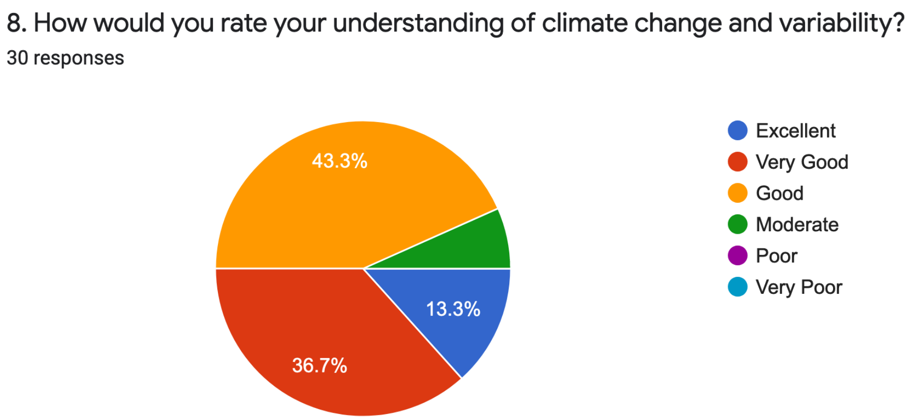


Figure 40: Understanding of climate variability

A large number of respondents also indicated that they do not receive climate information. Liberia currently lacks the hydromet capacity to guide national planning in priority areas such as agriculture and food security, health, water resources, disaster risk reduction, energy and transportation.

The major climate hazards reported from the survey is consistent with what is reported in the literature and the national policy documents. Flood, coastal erosion, and windstorm were the three most common climate hazards in Liberia (see Figure 2) and the frequency of occurrence of these hazards is seasonal

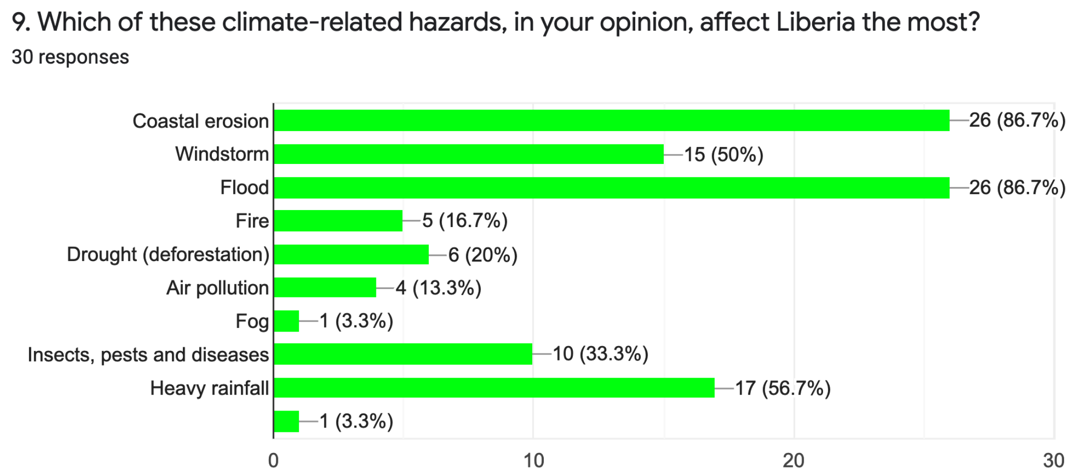


Figure 41: Common climate hazards in Liberia

Most people also reported having direct experience with a climate hazard (Figure 3). This shows how common the impact of climate hazard is among the populace.

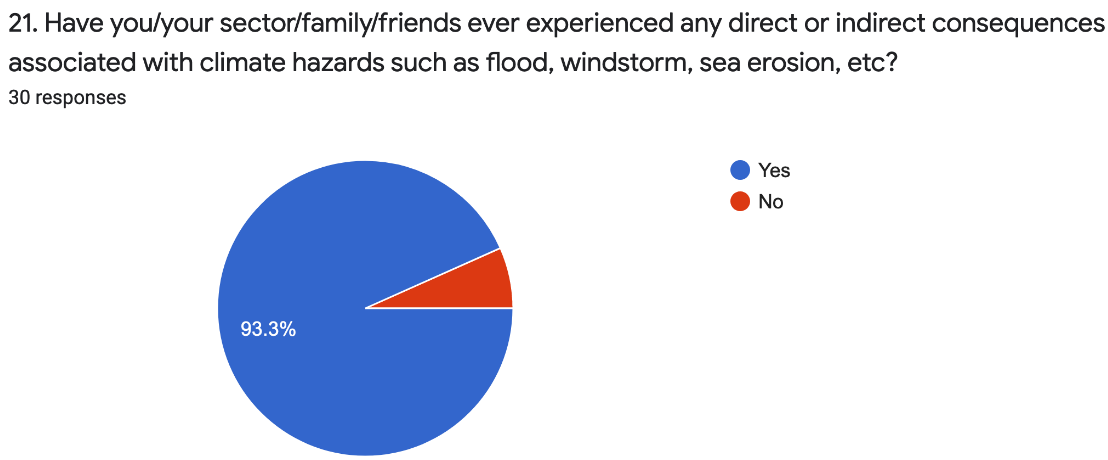


Figure 42: Direct or indirect experience with climate hazards

There was also unanimity among respondents on where or not climate hazards impact the different genders differently. The results (Figure 4) revealed nearly all respondents acknowledging that there are different levels of climate impact on men and women.

23. In your experience/opinion, does specific hazards (sea erosion, flood, windstorm, fire, drought, etc) affect men, women, children, and the elderly differently?
30 responses

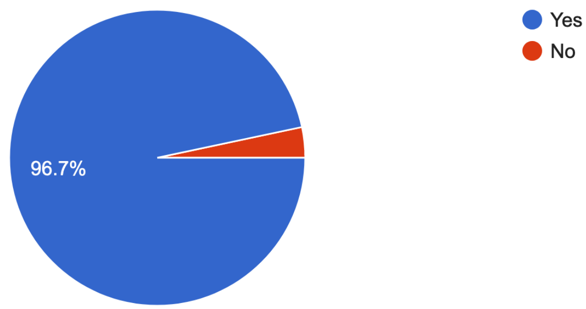


Figure 43: Impact of climate hazards on different genders

Most respondents indicated that women and children are most vulnerable to climate hazards. One of the reasons for this impact disproportion includes the limited resources available for women and children to build and sustain their resilience. Also, their occupations are largely in the climate-vulnerable sectors, and they do not have the economic resources to hedge the impact of climate hazards.

The situational analysis of climate information environment in Liberia showed strengths and weaknesses that currently exist, as well as opportunities and threats that can affect the future climate information services in the country. The outcome of the situational analysis is summarised in Table 1.

Table 1: SWOT Analysis

Strengths	Opportunities
i. Liberia's active membership status in international organisations such as the World Meteorological Organization grants it access to information and expert resources and result in direct benefits on hydro-meteorological methodologies, tools, and data. ii. In the past, Liberia succeeded in procuring financial assistance to build climate information structure; hence there is some capacity at the foundation to build on. iii. There is also continued support from local and international governments and institutions to develop the hydro-meteorological services. iv. Liberia has access to a range of international institutions that are ready to provide technical training for local hydrometeorology staff.	i. Liberia's Pro-Poor Agenda for Prosperity and Development (PAPD) can garner support for climate information services since the challenges of the poor relate contain weather and climate dimensions across sectors. ii. There are support efforts from the government, citizens and institutions to reduce climate disaster risks as is expected of them under the Sendai Framework for Disaster Risk Reduction 2015-2030. iii. The national support and commitment to pursue the sustainable development goals at the national, institutional and individual level presents a unique opportunity for accelerating climate information services. iv. There is a demand for climate information services in the country. This makes it easier to disseminate climate information to the general public for action.

v. There are available land and space at vantage points to build and operate hydromet stations.	v. There is a projected increase in the needs of aviation traffic. Also, neighbouring countries such as Guinea and Sierra Leone are also ill-equipped and can become major clients in Liberia's climate information services.
Weaknesses	**Threats**
i. There is limited historical data, climate database management system, telecommunication systems, and public weather services. ii. There is no robust and dedicated internet to support access to products from advanced centres and to share climate data and information. iii. The observation network destroyed during the conflict has not been re-established, and the available stations do not cover the entire country. iv. There are limited human resources (instrument technicians, engineers and trainers), and no radar to support newscasting and issuance of weather alerts. v. Low budget allocation is made for building infrastructure to monitor weather and climate, collect observations and process the data to generate forecasts and warnings.	i. The funding available for tackling climate issues in the country remains inadequate. ii. There is a challenge resulting from the inability to expand or upgrade the existing infrastructure to adapt to present demand. iii. The diverse range of users of climate information services means diverse climate products for different user-range. iv. A distrust in climate information services jeopardises the benefits of climate information communication. v. There are evolving models to provide services to the aviation sector and the associated demands from the International Civil Aviation Organization (ICAO), thus limiting the economic return of local climate information services.

2.2 Climate change risk, impact, and vulnerability analysis of the project

The information in Table 2 depicts climate risks hazards, the vulnerable sectors, as well as the priority sectors of Liberia, are identified in the country's Nationally Determined Contribution (NDC) in its National Adaptation Plan (NAP).

Table 2: Key climate risks and identified sectors in Liberia's NDCs

Country	Climate Risks					Total	Vulnerability					Total	Priority sectors					Total
1 = mentioned in NDC; 0= not mentioned in NDC	Extreme weather	Floods	Droughts	Temperature increase	Sea level rise		Agriculture	Water	Health	Ecosystems	Coastal zones		Agriculture	Water	Health	Biodiversity/ecosystems	Forestry	
Liberia	1	1	0	1	0	3	1	0	1	0	1	3	1	1	1	0	1	4

The top five climate risks in the NDCs submitted globally includes extreme weather, floods, droughts, temperature increase, and sea-level rise. Liberia mentioned three of these in its NDCs Also, the top-five climate vulnerability sectors that most countries identified in their NDCs are agriculture, water, health, ecosystems, and coastal zones while the priority sectors include agriculture, water, health, biodiversity/ecosystems, and forestry. Liberia mentioned three and four of the top-five global vulnerability and priority sectors, respectively, in its NDCs. This suggests that climate risks are of major concern in the country, and key economic sectors are exposed to these risks and are most vulnerable to climate hazards.

2.3 The political and legal environment

An assessment of the political, economic, socio-cultural, technological, legal, and environmental (PESTLE) factors of Liberia that has the potential to impact upon the project is, is presented in Table 3.

Table 3: PESTLE Analysis

Political Factors	**Economic Factors**
• Ability to contribute to the efforts to achieve the aspirations of the Pro-Poor Agenda for Prosperity and Development (PAPD), sustainable development goals, decisions of World Meteorological Congress, Sendai Framework for Action on DRR, African Union Agenda 2063, climate change agenda and ICAO. • Potential for low budget allocation; and • Goodwill from the government to revive and improve meteorological services in the country.	• Potential to lose revenue from the aviation sector due to inability to provide meteorological services that meet WMO, ICAO and IATA Standards. • The potential to have airports and Liberia airspace rated unsafe due to inadequate meteorological services. • Potential of having infrastructures designed and developed without adequate meteorological information leading to their inability withstand severe weather and extreme climate events resulting in losses in investments; and • The volatile global economy and potential effects on the national economy.
Socio-cultural Factors	**Technological Factors**
• Contribution of meteorological services to safety of life and property, disaster risk reduction, improvement in health outcomes, economic growth, water resource management, agriculture and food security, fisheries, forestry, renewable energy, safety and economic operation of air, water and road transport and enhancing the resilience of citizens, institutions and economy to climate change; • The needs for weather and climate services to support efforts to adapt and mitigate climate change. • Weather and climate risks associated with the growth in urbanisation and expansion of settlements into high-risk zones. • Growing demand for high-quality services. • Rapidly changing needs of users. • Demographic changes; and • Attitudes toward meteorological and hydrological services.	• Having the required scientific, technological and human resource capabilities to monitor, forecast and issue warnings of severe weather and extreme climate events and to fulfil WMO priorities. • Understanding and integrating the needs of various user communities, including emergency management authorities, into forecasts and warning programmes. • Ability to provide quick, timely, accurate, broadly disseminated and understandable information as well as high-quality services to inform governments and the public. • Participation and access to research that leads to improved monitoring, predictions and understanding of the changes in weather, climate, water and the related environmental conditions at all spatial and temporal scales. • Building new partnerships with academia, government departments, international and non-governmental organisations, the private sector and civil society. • Implementing ICAO Global Air Navigation Plan (GANP) and related Aviation System Block Upgrades (ASBU). • Impact of AWOS on the staffing levels; and • Implementation of WIS and WIGOS.
Legal Factors	**Environmental (ecological) Factors**
• The legal status of an LMS and its mandate. • Meeting standards for hydroment services; and • Data sharing and management policies.	• Ability of LMS to contribute to efforts to reduce the impacts of land degradation, heatwaves, floods, drought, and sea-level rise. Increased occurrence of severe weather and extreme climate events and associated impacts; and • National Environmental Action Plan.

2.4 Recent projects to build upon (EWS)

The project will leverage on the achievements of the just ended Early Warning System (EWS) projects to build effective climate information systems to provide relevant and timely climate products and services needed to inform climate-resilient development in Liberia. Though efforts of the EWS project to revitalise the hydromet sector destroyed by the 14-year civil war is significant, the country still lacks the capacity to provide meteorological and hydrological services required to guide national planning in priority areas such as agriculture and food security, health, water resources, disaster risk reduction, energy and transportation. There is limited infrastructure to gather, access, share and process data to provide weather and climate forecasts. There is also a limited number of qualified staff to operate the infrastructure; hence, a lower capacity to provide climate services to meet the increasing demand for climate information in virtually every sector of the Liberian economy. Further, the project will improve on the preceding initiatives to ensure effective generation and coordination of climate information and services to support informed decision-making processes in public and private sectors. Also, the project will sustainably transform the status quo of climate business in Liberia into a technologically driven end-to-end service delivery to private corporations, and potentially attract neighbouring countries interest in improving outcomes in climate-sensitive sectors.

3 Pre-feasibility Assessment

The environmental scan involved conducting SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to identify the strengths, weaknesses, opportunities, and threats of the LMS. The PESTLE (Political, Economic, Socio-cultural, Technological, Legal and Environmental (Ecological)) analysis was used to understand factors in the external environment that would influence opportunities and threats to the LMS.

3.1 Environmental, economic and social assessments

The project will provide environmental, social and economic benefits, including gender impacts to Liberia by providing means to avoid losses from increased climate variability and climate extremes due to climate change.

Environmental benefits

The project will indirectly support the development of a vibrant and sustainable environment by enabling accurate predictions for better flood management and risk-informed planning of agriculture and fisheries, strengthened ecosystem resilience and improved soil, air and water quality. For example, farmers and fishers will have access to relevant data that can guide their planning and decisions. Through short- and longer-term forecasting, farmers will gain knowledge and adapt their practices to be more effective, economical and precise.

Social benefits

The project will provide early warnings and climate information to improve health, safety, comfort and security of the most vulnerable people and communities living along the vast coastline prone to coastal erosion. This, in turn, will positively affect people’s health and well-being, and thus benefits communities and social structures by reducing the number of affected households, deaths and homelessness associated with hydromet-related disaster events.

Economic benefits

The project will strengthen the national hydro-meteorological infrastructure and forecasting abilities of the hydromet staff. This will improve the accuracy and spatial coverage of available climate information for providing tailored, sector-specific needs and people vulnerable to the impacts of climate change. This project will equip the LMHSs to deliver their core mandate and climate-resilient national planning and development necessary to improve economic outcomes.

Gender benefits

Women comprise more than 50.2% of the total people engaged in agriculture, forestry and fishery in Liberia[2]. Of the targeted, 1.5 million beneficiaries particularly in the main economic sectors including agriculture, forestry, fishery, construction and transportation across the country, the project aims to benefit more than 50% of women (about 132,000) through gender-differentiated vulnerability analysis, focused capacity building through the extension workers and participatory design of products, and gender-sensitive adoption strategies.

3.2 Financing options description.

The sole funding source to implement this project is the Green Climate Fund. The limited fiscal capacity to deal with a wide range of competing for national priorities justify the importance of GCF funding to transform the hydromet sector. Further funding sources and the defined self-sustenance potentials will ensure that the proposed interventions would be financially sustainable beyond the current phase. Again, as a Least Developed Country and a Low-Income Economy, there is limited capacity in Liberia to underwrite the cost of investment. The project will also strengthen Liberia's capacity to generate, process, disseminate and archive hydrological and meteorological information; the fourteen years of civil war destroyed its infrastructure. Liberia is among the countries most vulnerable to the impact of climate change. The public- good nature of the solution to address the current deficiencies in climate observation systems and dissemination platforms entails limited cost recovery from the proposed measures to save lives and livelihoods of vulnerable populations in the country.

3.3 Economic and financial viability

Liberia, like many developing countries, does not have a robust database of crucial socio-economic variables that are required to make concrete predictions of the outcomes of different climate policy measures. As part of the outcomes, this project will build a data repository that contains a systematic track record of the changes in micro socio-economic indicators and link them to specific policy actions from which they emerged. One of the

[2] Liberia Labour Force Survey (2010)

methodologies that will be employed to conduct this exercise will be system dynamics modelling.

Jay Forrester developed system Dynamics at the Massachusetts Institute for Technology in the late 1950s. Causal relations, feedback loops, delays and non-linearity are integral themes of this methodological approach, making it particularly suitable for representing and analysing complex real-world systems. Through the explicit representation of stocks and flow, system dynamics models run differential equations to generate future scenarios. This methodological approach is capable of identifying key economic sectors, eliciting the variables of each sector, illustrating their relationships within and across sectors, and revealing the embedded feedback processes that are not overtly understood or often not captured by standard regression models.

The procedures involved in constructing a system dynamics model are similar to and aligned with the steps employed at the United Nations (UN) integrated policymaking cycle. A five-step iterative process is involved in developing a system dynamics model: (1) problem identification, (2) dynamic hypotheses, (3) formal model development, (4) validation and (5) simulation of alternative scenarios. The system dynamics process shows the role of feedback loops in shaping future development and contributes to analysing trade-offs and potential undesired policy side-effects. System dynamics models are used to simulate exploratory 'what-if' scenarios to assess potential policy interventions and development trajectories, as opposed to other approaches that focus on optimisation. The results of such an analysis reveal potential future impacts of policy interventions (desired and undesired) as well as the complementarity of policy interventions in achieving specific objectives.

System dynamics modelling is used to compute some key climate impacts in the past, present, and potential future scenarios based on the limited data available currently. System dynamics, unlike many other economic models, maps out the full feedback loops that exist among the different variables associated with a given problem. The model developed for this feasibility assessment is labelled the Liberia Climate Risk Assessment Simulation Model (here forth referred to as LICIAM).

The causal loop diagram in Figure 1 is a simple depiction of the qualitative part of the model showing the relationship between some key variables concerning climate hazards. The arrows show the direction of cause and effect, while the polarity notation of's' and 'o' at the end of each arrow shows the nature of the effect, where's' means the same direction and 'o' represent an opposite direction.

In Figure 5, when GDP growth increases, GDP will also increase, hence 's', and when GDP increases, the Loss to GDP ratio will decrease, hence 'o'. An increase in the Loss to GDP ratio will result in a decrease in GDP growth. This cycle of the feedback loop is named the economic loop. The 'R1' notation means reinforcing loops. A loop is reinforcing when the net outcome of the relationships is positive or moves in the same direction. In the Climate loss loop, the 'B1' notation means a balancing loop. This is where the net outcome of relationships is negative of moves in the opposite direction.

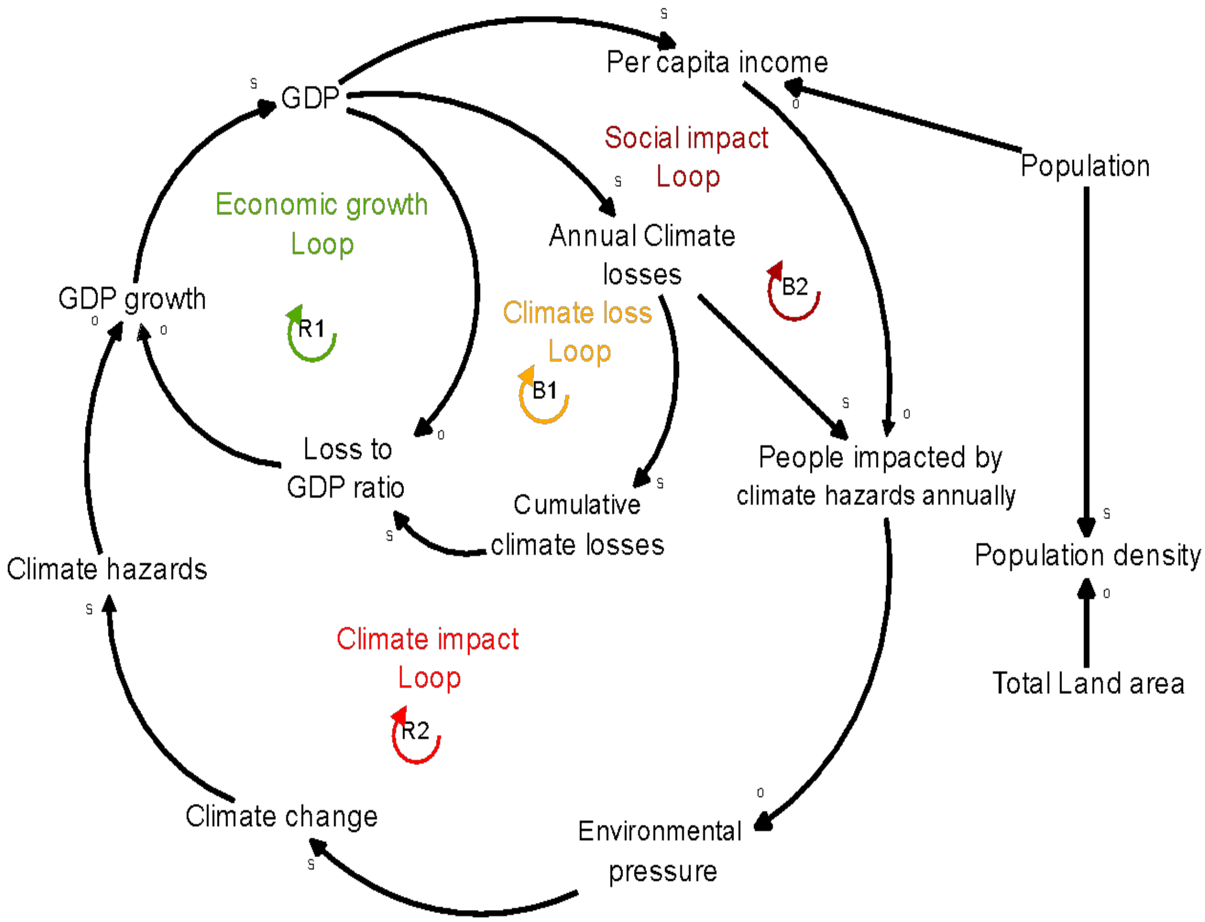


Figure 44: Causal Loop Diagram

The outer loop of the diagram depicts the relationship between GDP, per capita income, and climate change. When GDP increases, the per capita income of the country will also increase. An increase in per capita income will reduce the impact of climate hazards as people will have the economic resources to adapt. When more people are impacted by climate hazard, there will be more pressure on the environment since more effort will be required to sustain normal living status. An increase in environmental pressure will accelerate climate change, which will lead to more climate hazards, less GDP growth, and eventually feedback to GDP. This modelling approached allows for the representation of the remote effects of multiple variables on each other, leading to a much accurate depiction of real-world experiences.

There is usually an attempt to recreate the historical dynamics to build confidence in the model. The historical data of different variables can be compared with that of the model results over such period as a validation mechanism. It must be noted that consistency between the model and data does not necessarily mean that the model is valid. It only implies that the model cannot be rejected solely based on a lack of consistency with data. As such, there are other validation exercises. Structural validation ensures that the model structure, such as the relationship between the variables, represent the real-world case. Other validation test includes extreme condition test, behavioural test and sensitivity analysis. The result of the key variables identified in the model is discussed next.

The quantitative model was simulated, and seven different scenarios were assessed to ascertain some potential impact of climate change in Liberia. The different scenarios and their descriptions are provided in Table 4. The simulation covers a period of 35 years; from 2006 to 2040. The period from 2006 to 2019 is regarded as the base period.

Table 4: Scenario descriptions

Scenarios	Description
Baseline	This refers to the business-as-usual case where no different action is taken to cause a change in the current path.
25% loss increase	This is the case where there is a 25% increase in the fraction of GDP that is lost annually as a result of climate change within five years. This occurs between 2021 – 2025.
25% loss decrease	This is the case where there is a 25% decrease in the fraction of GDP that is lost annually as a result of climate change within five years. This occurs between 2021 – 2025.
50% loss increase	This is the case where there is a 50% increase in the fraction of GDP that is lost annually as a result of climate change within ten years. This occurs between 2021 – 2030.
50% loss decrease	This is the case where there is a 50% decrease in the fraction of GDP that is lost annually as a result of climate change within ten years. This occurs between 2021 – 2030.
75% loss increase	This is the case where there is a 75% increase in the fraction of GDP that is lost annually as a result of climate change within fifteen years. This occurs between 2021 – 2035.
75% loss decrease	This is the case where there is a 75% decrease in the fraction of GDP that is lost annually as a result of climate change within fifteen years. This occurs between 2021 – 2035.

Annual Losses due to climate change/hazards

There is a growing amount of climate risks and associated costs in Liberia. As major climate hazards such a flood, coastal erosion, windstorm, among others become frequent, the annual amount of loses in monetary value has increased. According to Kreft, Eckstein et al. (2013), Liberia loses approximately 0.02 per unit GDP from 1994 to 2013. This resulted in an estimated loss amounting to US$3.79 million in 2013 and US$ 7.44 million in 2017 (Eckstein, Künzel et al. 2017). The number of losses attributed to climate hazards in Liberia as of 2014 was US$6.34 million (PreventionWeb 2014).

The annual cost of climate in LICIAM was computed using GDP and fraction losses rate. GDP was used as a proxy because of the lack of data at the micro-level as to the monetary value of specific climate disasters in the country. The losses per unit GDP was derived from the annual climate risks reports published by GermanWatch. The results of the simulation are shown in Table 5. Currently, approximately US$6.17 million losses are recorded in Liberia as a result of climate hazards. This figure is expected to almost double in the next decade, and triple by 2040 under the baseline scenario.

Table 5: Annual losses due to climate hazards

	Period of change			Annual Losses due to climate (in US$)						
Scenarios (change in fractional GDP Loss)	5 years (2021-2025)	10 years (2021-2030)	15 years (2021-2035)	2006	2019	2021	2025	2030	2035	2040
Baseline				2,566,000	6,171,000	6,554,000	8,764,000	11,527,000	14,948,000	18,236,000
25% loss increase	x			2,566,000	6,171,000	6,554,000	17,452,000	22,090,000	26,438,000	29,276,000
25% loss decrease	x			2,566,000	6,171,000	6,554,000	0	0	0	0
50% loss increase		x		2,566,000	6,171,000	6,554,000	30,407,000	57,035,000	57,845,000	57,845,000
50% loss decrease		x		2,566,000	6,171,000	6,554,000	0	0	0	0
75% loss increase			x	2,566,000	6,171,000	6,554,000	41,085,000	83,318,000	112,720,000	112,720,000
75% loss decrease			x	2,566,000	6,171,000	6,554,000	0	0	0	0

Under all the scenarios where the fraction of GDP loses decreases by a minimum of 25% within a period of five years, the annual losses (economic, excluding social) can be eliminated by 2025. However, in a situation where the fraction of losses increases, the annual losses to climate hazards will range between US$29.3 million under the 25% increase to 112.7 million under the 75% increase scenario by 2040. This will create an undesirable state of climate havoc. The graphical representation of these scenarios is illustrated in Figure 6.

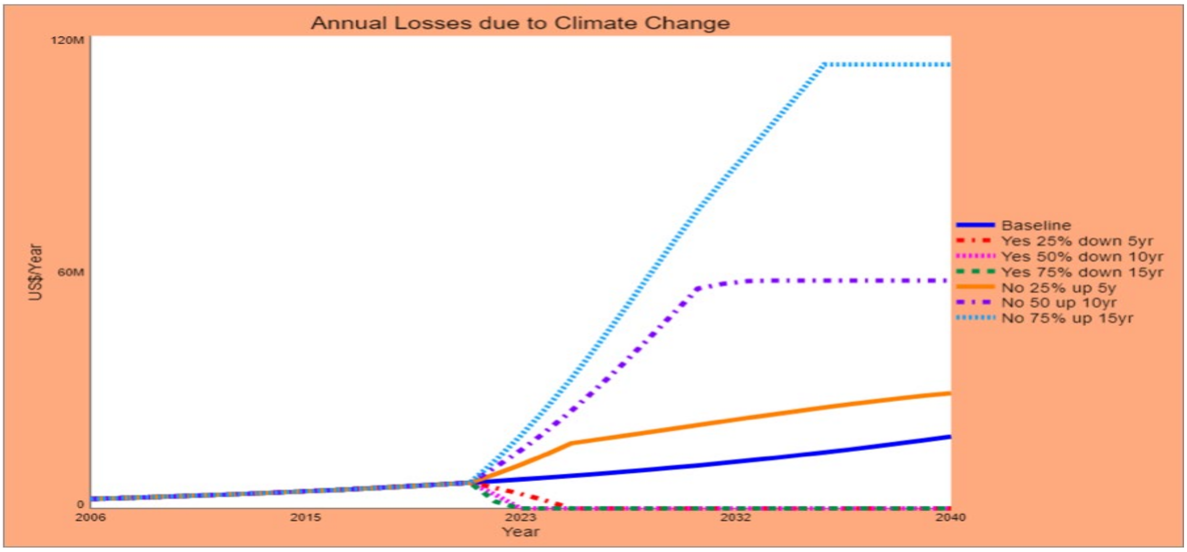


Figure 45: Annual losses due to climate hazards

People Impacted by climate hazards

There is paucity of data on the total number of people that are affected by different climate hazards in Liberia annually. The LICIAM, therefore, computes the number of people impacted by climate hazards using the annual losses and the per capita income. This formulation enabled the model to simultaneously make adjustment to all linked variables based on the changes experienced. The results of the people impacted are demonstrated in Table 6

Table 6: People impacted by climate hazards annually

	Period of change			People impacted by climate hazard annually						
Scenarios (change in fractional GDP Loss)	5 years (2021-2025)	10 years (2021-2030)	15 years (2021-2035)	2006	2019	2021	2025	2030	2035	2040
Baseline				6,825	9,408	9,643	10,911	12,344	13,966	15,416
25% loss increase	x			6,825	9,408	9,643	21,821	24,689	27,933	30,832
25% loss decrease	x	X		6,825	9,408	9,643	0	0	0	0
50% loss increase		X		6,825	9,408	9,643	38,187	67,894	76,816	84,790
50% loss decrease		x		6,825	9,408	9,643	0	0	0	0
75% loss increase			X	6,825	9,408	9,643	51,825	104,927	160,615	177,289
75% loss decrease			X	6,825	9,408	9,408	0	0	0	0

According to data from the GermanWatch, Liberia does not record high fatalities such as death, as a result of climate hazards. The annual climate fatality in Liberia is less than one person (Eckstein, Künzel et al. 2017). In 2006, nearly 7,000 people in Liberia were impacted by climate hazards. This impact is often in the form of loss of economic or social capital such as houses, farm products, social networks, and relations, among others. Under the baseline scenario, the people impacted by climate hazards will increase 15,416 people by 2040. Response mechanisms that result in up to 25% reduction in the fractional losses within the next five years will ensure that the economic impact of climate is eliminated. The 25%, 50%, and 75% increase scenarios, however, will see the people economically impacted by climate hazards to rise to 30,832, 84,790, and 177,289 people, respectively, by 2040. The behavioural graph people impacted annually by climate hazard under the different scenarios is shown in Figure 7.

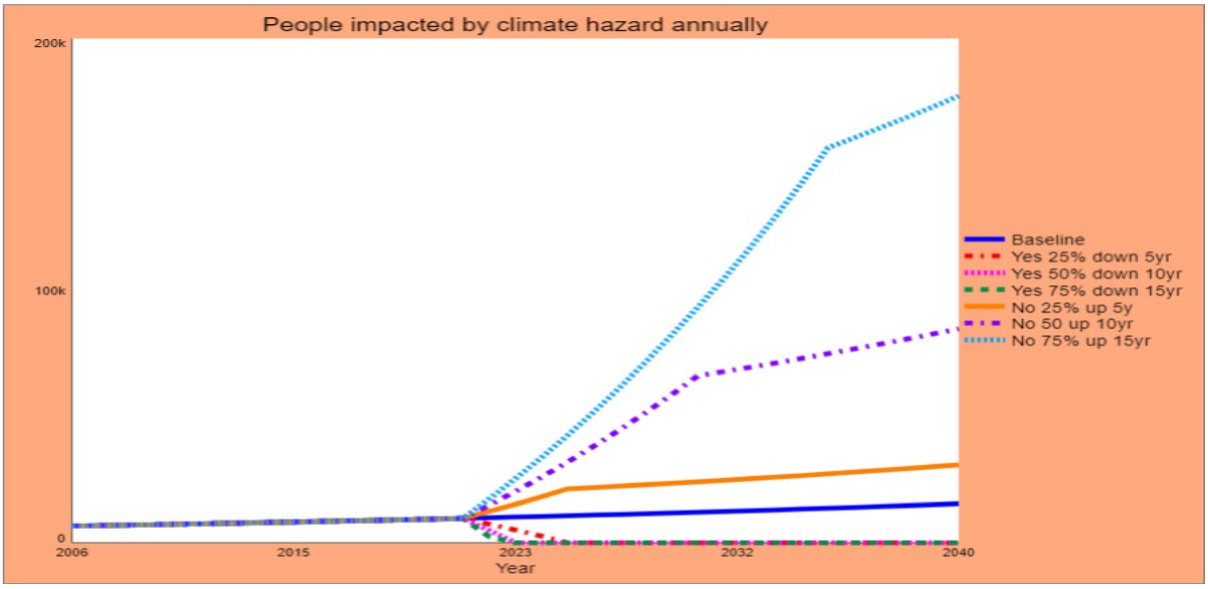


Figure 46: People impacted by climate hazards annually

Per capita income

The per capita income of Liberia increased steadily throughout the base period. In the baseline scenario, the per capita income is expected to increase from approximately US$ 680 in 2021 to US$ 934 by 2030 and US$ 1,183 in 2040 (see Table 7). The 25% increase and decrease of fractional GDP lost through climate hazard result in a per capita income of US$ 950 and US$ 1,431, respectively by 2040.

Table 7: Per capita income

	Period of change			Per Capita Income (US$)						
Scenarios (change in fractional GDP Loss)	5-years (2021-2025)	10 years (2021-2030)	15 years (2021-2035)	2006	2019	2021	2025	2030	2035	2040
Baseline				376	656	680	803	934	1,070	1,183
25% loss increase	X			376	656	680	800	895	946	950
25% loss decrease	x			376	656	680	807	973	1,198	1,431
50% loss increase		X		376	656	680	796	840	753	682
50% loss decrease		X		376	656	680	810	984	1,218	1,460
75% loss increase			x	376	656	680	793	794	702	636
75% loss decrease			X	376	656	680	811	987	1,223	1,467

The differences in per capita income under the different loss decrease scenarios is small throughout the simulation period. For example, under all the 25%, 50%, and 75% loss decrease scenarios, the per capita income in 2030 is US$ 973, US$ 984 US$ 987, respectively. This is because of the differences in the duration of change. The behavioural graph in Figure 8 depicts this similarity in the outcome of these scenarios.

The differences in per capita income under the different loss decrease scenarios is small throughout the simulation period. For example, under all the 25%, 50%, and 75% loss decrease scenarios, the per capita income in 2030 is US$ 973, US$ 984 US$ 987, respectively. This is because of the differences in the duration of change. The behavioural graph in Figure 8 depicts this similarity in the outcome of these scenarios.

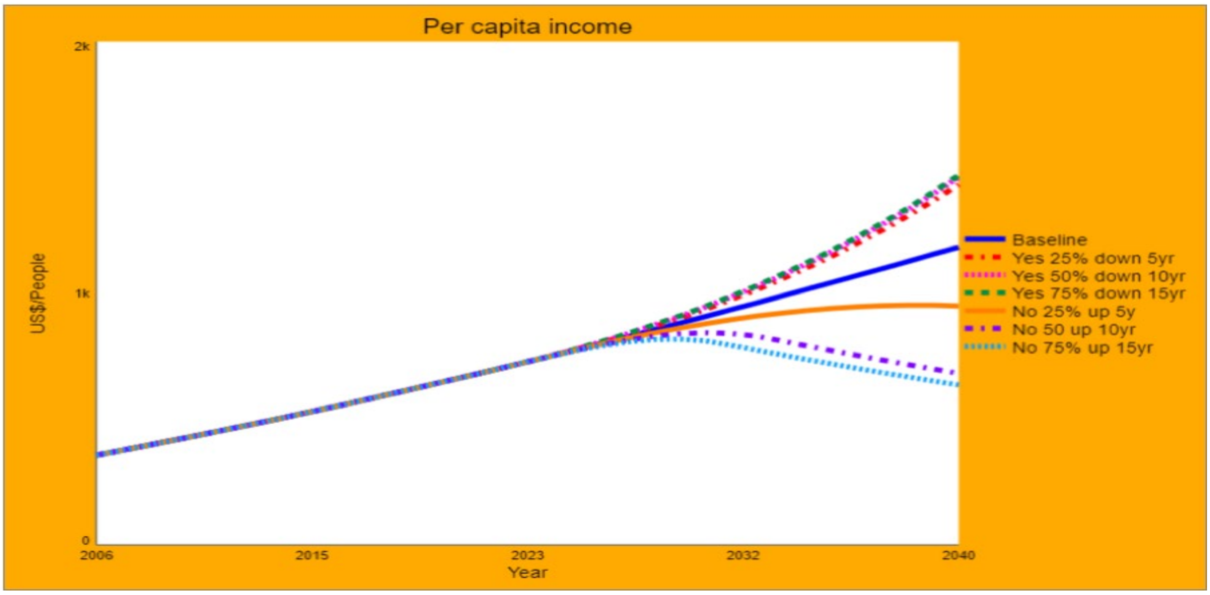


Figure 47: Per capita income

The sensitivity analysis revealed per capita income as one of the variables most sensitive to changes in the fraction of GDP recorded as climate losses. This is because per capita income is influenced by two major dynamic variables; GDP and population. The GDP and GDP growth are also significantly affected by climate hazards as economic activities are hindered.

Various social losses are not quantified in this model. The interpersonal relationships, the cultural activities and artefacts, the social networks, among others and not accounted for in this model. The losses presented are most likely to be an understatement rather than overestimation. Although the monetary value of climate hazard computed in this proposal may appear small, there are three critical reasons why this project is critical and should be funded:

1. The project is a sound economic investment because the returns on investment are financially profitable than the baseline scenario where this project is not executed.
2. Liberia is one of the Least Developed Countries in the world. These losses accruing from climate hazards are a menace to the country's economic output,

and when juxtaposed with the annual GDP, a significant improvement in GDP growth rates will be realised.
3. The financial analysis in this proposal mainly focused on the economic aspect. The social cost of climate hazards, such as death, diseases, and loss of productive working hours, among others, are not quantified. That lack of socio-economic data of Liberia makes such estimates difficult. This is one of the key gaps this project responds to in its planned outputs.

The components and outputs elaborated in the proposal will lead to a climate-resilient outcome for Liberia. The project will aid in reducing the annual climate losses, result in fewer people being exposed to and impacted by climate hazards, and increase the per capita income of the country in general.

3.4 Exit strategy and sustainability

By the end of the GCF project, LMS, LHS, EPA, NDMA, will be institutionally, technically, and technologically equipped and trained to collect weather and climate data. The agencies will be able to introduce and maintain modelling, forecasting and early warning systems to scale-up evidence-based climate-informed decision-making, planning, and response actions countrywide.

The project outcomes align with the priorities of Liberia Country Strategic Plan (2019-2023), which seeks to integrate green growth, environmental resilience, and adaptation into national development planning through effective climate information systems. The outcomes are also consistent with the goals of Liberia's National Vision 2030, which aims to reduce poverty, promote social, economic development, and reduce the impact of weather and climate-related disasters in the country. The project will contribute to the efforts of the Government of Liberia to both reduce the vulnerability of its population to weather and climate risk and to ensure the sustainable development of the country. It will also strengthen the hydro-meteorological sector's ability to contribute to the objectives of Liberia's National Development Plan.

In light of the above, the participating departments—EPA, LMS, LHS and NDMA—will fully integrate project activities into their budgets. These agencies will submit annual budgets to the Government of Liberia. The budgets will cover expenses related to the operation and maintenance costs for the meteorological and hydrological monitoring and data management equipment. The budgets will also support activities related to weather and climate monitoring, forecasting and warning, flood monitoring, and research and development on atmospheric, geophysical, astronomical, and allied sciences, and general administration operations. Last year, the Government of Liberia allocated 1.3 million US dollars for these activities. The LMS and LHS will install weather, climate and hydrological observing and monitoring equipment on their designated weather and hydrological observing stations (e.g. synoptic, agromet, etc.) strategically located across the country. This will help ensure the security and continuous operations of the facilities and equipment.

The LMS will procure and install Automatic Weather Stations (AWS) during the first year of implementation. The estimated total unit cost is 10,000 US dollars, including installation works. The land requirement for AWS and tide station are 36 m2 and 9 m2 respectively. A typical synoptic station has a lot area of at least 500 m2. The project will install AWS' in local government-owned properties such as state universities etc. A Memorandum of Understanding (MOU) will be executed between LMS/LHS and the concerned local governments and institutions to ensure the security and continuous operations of the facilities. The MOU will include a clause related to the local population's agreement to keep watch over the installed equipment, thereby ensuring a sense of ownership of the system on the part of the local communities. Notwithstanding, the LMS/LHS will still regularly check and maintain the system.

Both the LMS/LHS have learned lessons when it comes to protecting their investments in equipment and facilities, which they will leverage to ensure the sustainability of the current project. One significant lesson is that the installation of AWS on mobile phone towers and ground stations, is not suitable for METAR or SYNOP reports (report of surface observation from a land station – code form). The tower affects wind speed, direction, temperature and rainfall. This approach also incurs unnecessary costs for the LMS.

The AfDB, through its Climate and Development Special Fund (CDSF), launched a 400,000 Euros project to improve the weather and climate observation network, build the capacity of LMS. The produce and deliver weather services and provide weather forecasts and warnings to the public and other users. They will purchase and install various climate observation equipment for the LMS. The AfDB will ensure that the quality of after-sales services of the supplier as part of the selection criteria for the provider. This is to increase the sustainability of goods procured for this project. The project will also support LMS in procuring four-wheel vehicle fitted with a calibration unit to monitor the operation and conduct regular maintenance of all equipment and facilities the department has installed around the country. Lastly, LMS will make it its policy that only well-trained and approved specialists will operate and maintain all procured equipment. The GCF project applies these same sustainability measures to all equipment installed and procured through this GCF project. As properties of LMS (including the Aviation sector)/LHS, the equipment procured with GCF funds will become a part of their observing networks. They will, therefore, be included in the Operations and Maintenance Plan as well as the yearly budget allocations of their respective ministries.

The availability of weather radar and lightning-detection networks techniques for short-term prediction of thunderstorm movement mitigate the impact of weather in disrupting air traffic management and airline operations at airport and airspace. The capacity building that will be provided by the AfDB project will improve numerical weather prediction (NWP) and offer great opportunities for enhancing weather services for aviation. It will also improve the capacity of LMS to disseminate in real-time operational aeronautical meteorological data (OPMET), including METARs, TAFs and SIGMETs/AIRMETs. The AfDB will also support the implementation of the Quality Management System (QMS) requirement for Roberts International Airport (RIA). Hence, both the AfDB and GCF projects will build the capacities of the LMS and LHS will work towards charging fees in Meteorological services, weather forecasts, warnings and other information, for the needs of civil aviation. Other areas include: weather forecasts and warnings for marine activities, agriculture and fisheries in the sea area of Liberia; and supply of meteorological information and consultative services for the needs of the Liberia community and in particular for applications to agriculture, conservation and management of water resources, engineering studies and constructions, tourism and industry, renewable energy sources, environmental studies

Several donor projects are currently ongoing or under preparation to strengthen the capacities of the meteorological and hydrological services. This GCF project will ensure that it takes advantages of synergies with similar projects, including those financed by USAID CRUZ and WMO to consolidate the implementation of activities and increase sustainability.

Component five will provide political support to allocate necessary resources by the government to sustain project results. Enhancing ownership by local administration will be done through an MOU. The local administration will provide a safe and secure location for the installation of early warning equipment and will be responsible for the maintenance of the equipment.

The improved capacity of communities under Component Two to use climate risk information in their planning processes and practical early responses to impending extreme weather events will strengthen the sustainability of the climate knowledge and applications generated.

The project includes a strong focus on community engagement, training and “Last Mile” communication solutions to elevate understanding of climate risks and achieve sustainable change in behaviour among local communities. Establishment and operationalisation of national and local coordination mechanisms will ensure that all stakeholders know what to do, when and how. Participation of other partners (e.g. NGOs, private sector, and academic institutions) will further promote the long-term sustainability of results. Due to the huge awareness created by this project on the importance of climate and weather information services in planning and development, The project will pave the way for greater involvement of the private sector in the delivery of climate information products and services, risk transfer schemes and risk reduction.
Beyond the project’s life, LMS, LHS and NDMA will continue to provide impact-based forecasts and warnings nationwide. At the local level (e.g. counties/parishes), LMS, LHS, NDMA and their co-executing entities will continue to assist other urban areas surrounding the project sites and corresponding counties to develop downscaled risk matrices with impact and response tables in a participatory manner. The fact that the agencies will be responsible for covering their respective operating and maintenance costs guarantees the long-term sustainability of the project’s investments beyond its completion.

4 Specific information on the project

The Early Warning System (EWS) project built some weather stations and trained some personnel to manage them. This project intends to build as well as up-scale on the existing infrastructure and human resources available to provide relevant and timely climate products and services for climate-resilient development in Liberia. It will aid national planning in priority areas such as agriculture and food security, health, water resources, disaster risk reduction, energy and transportation. The project will also promote the effective generation and coordination of climate information and services to support informed decision-making processes in various spheres, transform the status quo of climate business in Liberia into a technologically driven end-to-end service delivery to private corporations, and potentially attract neighbouring countries as clients for climate information services.

4.1 General Overview of Liberia

The Republic of Liberia is a relatively small country with a land area of 111,369 km^2 located within the humid Upper Guinean Forest Ecosystem in West Africa on the Atlantic Coast. In terms of land area, Liberia is the fifth smallest country on the African Continent. The extreme southeast of the county is closer to the equator than any other coastal part of West Africa (Wiles 2005).

Liberia is located within latitudes 4°21' - 8°33' N and longitudes 11°28' - 7° 32'W bound. The country's borders consist of 15,050 km^2 of water and 96,319 km^2 of land. The perimeter of Liberia is 2,551 km (UNDP 2006), and shares a border with Côte d'Ivoire, to the east with a shared border length of 598 km; Sierra Leone, to the west with a shared border of 370 km; Guinea, to the north with a shared border of 540 km; and the North Atlantic Ocean, to the south with a vast coastline (Wiles 2005). The coastline extends for about 560 km from Cape Palmas in the southeast on the border with Côte d'Ivoire northwest beyond Robertsport to the Mano River on the border with Sierra Leone. The area of Liberia's Exclusive Economic Zone (EEZ) is 229,700 km^2, extending 370.4 km (200 nautical mi) seaward from the shore. The width of the continental shelf is generally limited by the 100 m isobath, being wider off central Liberia. The major seaports are Monrovia, Montserrado County, and Buchanan, Grand Bassa County (Wiles 2005).

4.1.1 Environmental Structure

This section gives a brief description of the physiology, soil, land cover/vegetation zones and river and wetland systems[3] of Liberia.

a. Physiology - Liberia has four main physiological regions characterised largely by increasing elevation (Figure 9). These physiological regions include the Coastal Plain, the Rolling Hills, the Mountain Ranges and Plateaus, and the Northern Highlands (Gatter 1997). They are oriented parallel to the coast. The Atlantic Ocean surface waters of Liberia lie between the Canary Current area to the northwest and the Benguela Current area to the east. The water surface is uniformly warm (26–28°C) with low salinity because of heavy rainfall and high river discharge. Seasonal oscillation of the thermocline and nutrients occur according to the oscillation of the equatorial undercurrent (Brandolini and Tigani 2006).

b. Soil - Liberia lies wholly within the Humid Agro-Ecological Zone that stretches from West to Central and East Africa. Rainfall throughout the zone exceeds a mean of 1,500 mm/yr, and temperatures range between 24° and 28°C with a growing season length of more than 270 days. According to the FAO classification, dominant soils in the country are Ferralsols and Acrisols. These are Oxisols and Ultisols for Ferralsols and Acrisols, respectively, as indicated in the USDA Soil Taxonomy. About 4% of Liberia is covered by Gleysols (Histosols) that are typical of swamps and areas in the floors of valleys waterlogged during the rainy season. These soils have high humus content and suitable for cultivation of swamp rice, with proper water management (Brandolini and Tigani 2006).

[3] USAID (2013). Liberia Climate Change Assessment version 4. March 2013.

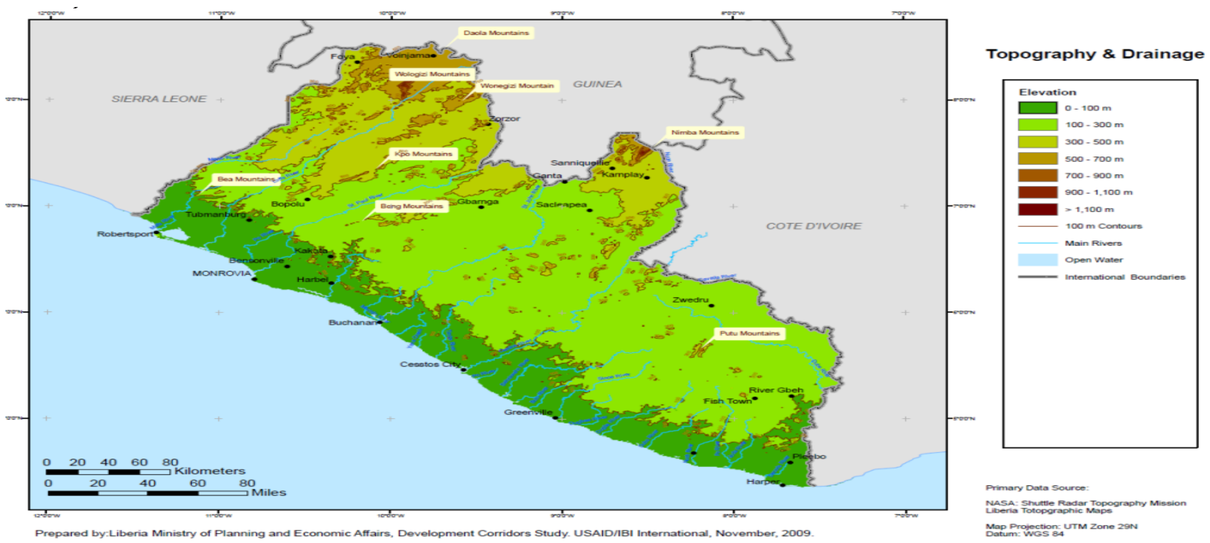


Figure 48: Map showing the topography and drainage of Liberia (Source: USAID 2013[4])

c. Land Cover/Vegetation Zones – Liberia lies within the Upper Guinean Forest. The Upper Guinean Forest is fragmented, and Liberia accounts for more than half of West Africa's remaining tropical forest. The total Liberian land area is 9.59 million ha, of which forests cover about 45% or 4.39 million ha (DAI 2008). About half of the forest area is classified as closed dense forest (2.42 million ha); 1.02 million ha are classified as open dense forest almost 1million ha are degraded or have been converted to agriculture (Table 8).

Table 8: Landcover condition (from Bayol and Chevalier 2002)

Land Cover Class	Area, ha	Percent of total land area (%)
Closed dense forest	2,424,078	25.3
Open dense forest	1,013,993	10.6
Agriculture degraded forest	949,615	9.9
Mixed agriculture and forest area	1,317,873	13.7
Agriculture area with small forest presence	3,042,091	31.7
Predominantly rural agriculture	436,747	4.6
Agro-industrial plantations	178,294	1.9
Savanna or bare soil	13,312	0.1
Littoral ecosystem complex	161,390	1.7
Open water	7,649	0.1
Urban	46,047	0.5
Total	9,591,089	100

The moist and wet forest blocks are separated by an extensive zone of degraded forest near the coast and extend inland in central Liberia. The coastal zone is heavily impacted by settlements and agriculture, with a mosaic of sandy and rocky shores, mangroves and

[4] USAID (2013). Liberia Climate Change Assessment version 4. March 2013.

freshwater swamps, grass/shrub savannas on the sand, and coastal forests. Figure 10 presents satellite-derived imagery of forest and land cover of Liberia for 2003.

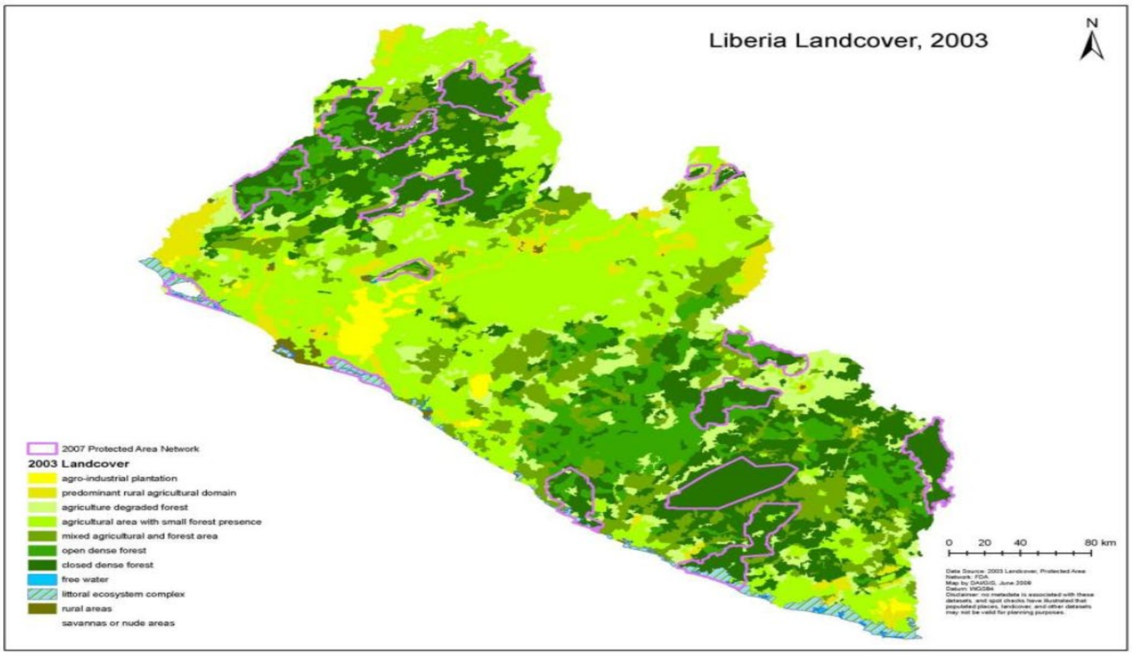


Figure 49: Land cover in 2003, interpreted from satellite remote sensing (Source: USAID 2013)

d. River and Wetland Systems – Available data on water resources in Liberia is limited. Before the 14year civil war in Liberia, the Liberia Hydrological Service (LHS) of the Ministry of Lands, Mines and Energy (MLME), collected basic hydrological and meteorological data from a network of 28 hydrological and 13 hydro-meteorological stations covering eleven river basins around the country. These stations were abandoned and damaged during the crisis, and they have not been re-established. Currently, the Norwegian Water Resources and Energy Directorate (NVE) Technical Assistance Programme project delivered 15 hydrometric stations as an intervention to revive the country's hydrological observing network. Also, 14 rainfall stations were re-established. It is expected that the rainfall network will be equivalent to half the capacity prior to the war when the number of functioning stations was 64.

Some of the georeferenced mean monthly stream discharge data that are available for internet download (IWMI 2010) include records for upper St. Johns River (1973-79, former gauge near Baila); a tributary to the upper St. Johns River (near Gbarnga); upper Loffa River (1973- 76, near Duogamai); upper River Cess (1976-83, near Sawolo, east of Tapeta); Sehnwehn River (1976-78, near the mouth, Tournouta-Bafu Bay); and Nianda River, upper St. Paul River drainage (1973-1975); Walker Bridge, north of Gbargna. More temporally extensive georeferenced monthly average rainfall data are available from the same source for Firestone Cavella (1929-1980); Harbel (1936-93); Nyaake (1952-73); Pinetown (1952-73); Tapeta (1952-73); Roberts Field (1951-84); Zia Town (1952-61); Zwedru (1952-73).

Liberia has six principal rivers that traverse the width of the country roughly from northeast to southwest (drainage area in parentheses): the Mano (6,604 km2), Lofa (or Loffa) (9,194 km2), St. Paul (12,820 km2), St. John (14,762 km2), Cestos (or Cess) (10,000 km2), and Cavalla (13,726 km2) rivers (UNDP 2006). These rivers drain about 65% of the country, and most are navigable ≤32 km from the coast, except for the Cavalla River, which is navigable ≤80 km from the coast. The Mano and Cavallo river basins are shared between Sierra Leone and Cote d'Ivoire, respectively. In addition, the Lofa, St. John, and St. Paul rivers drain part of Guinea (DAI 2008). Also, the country has several smaller streams. Among them are the Junk, Farmington, Po, Du, Timbo, Sehnkwelm, Sino, Dugbe, Dubo, and Grand Cess rivers and in total Liberia has 16 main river basins (Figure 9).

As expected, the seasonal cycle of extremes inflow in the rivers corresponds with the seasonal rainfall peaks and troughs associated with the West African Monsoons, as depicted by the Upper St. Johns River near Baila (Figure 11). The hydrograph peaks in September and October with a long, relatively steep descending limb occurring from November to May. The flow then increases consistently from March to September with the steepest increase in discharge occurring from July to September.

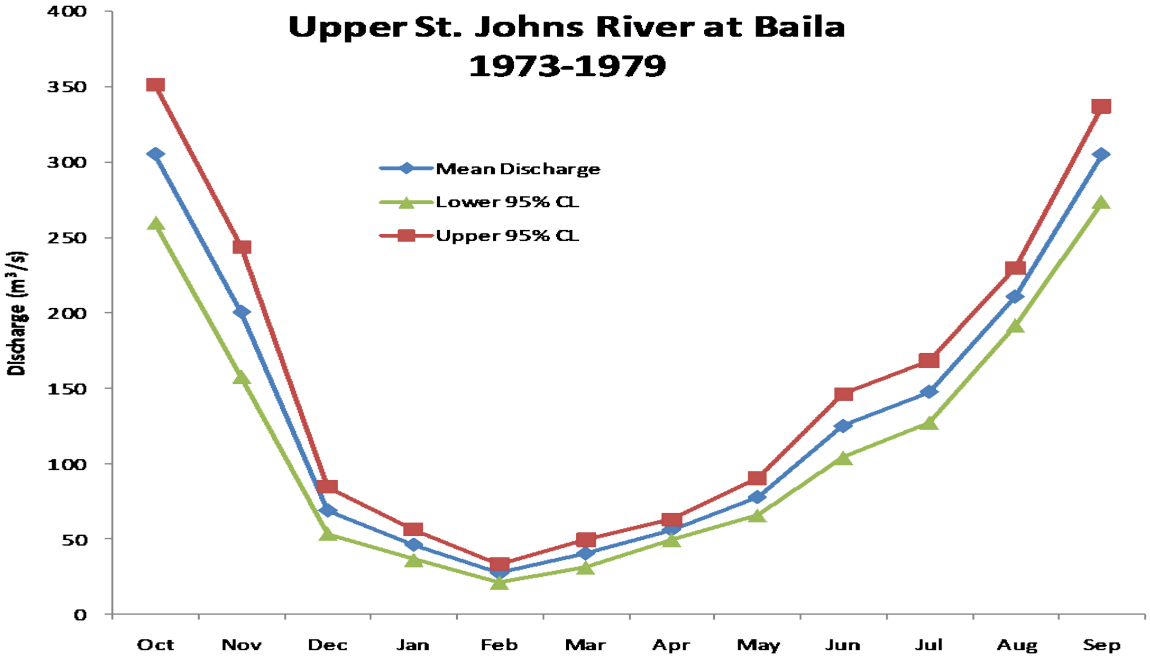


Figure 50: Hydrograph for the Upper St. Johns River at Baila, 1973-1979 (Source: USAID 2013).

Many kilometres of tidal riverbanks (3,092 km), creeks (645 km), and smaller tributaries (>1,000 km) are (or were) covered with mangroves reaching 30 m in height are situated near the coast. An estimated 600,000 ha of freshwater wetlands (swamps) occur in Liberia with only about 3% (20,000 ha) under cultivation (DAI 2008). The exit very limited knowledge about the specific values of freshwater wetlands in Liberia - including their role in providing medicinal plants, and other products, to their role in providing ecosystems services such as water quality enhancement, flood control, and provision of food fish habitat, nursery, and spawning areas important to artisanal (marine and freshwater) as well as commercial marine fisheries.

The largest lake in Liberia (about 22 x 12 km) is Lake Piso, primarily brackish water, open coastal mangrove lagoon with a maximum depth of about 4-5 m located in the west of the country near Robertsport, Grand Cape Mount County (Gatter 1997). The Marshall Wetlands, a coastal lacustrine, tidally influenced wetland of about 12,168 ha, are located in Margibi, and Grand Bassa counties within the Little Bassa, Farmington, and Du river basins and are listed as a wetland of international importance (Ramsar 2010).

The Mesurado River Wetlands, occupying 8,903 ha, sprawls across about 60% or more of the greater Monrovia area, Montserrado County. These wetlands are situated in the wettest area of Liberia, annually receiving over 4,500 mm of rainfall. The wetland water depth can range from about 1.5 m at low tide to 4.5 m at high tides; during the dry season,n depths are 1.0-1.5 m (Ramsar 2010). An estimated population of 970,824 people live in the Greater Monrovia district (LISGIS 2010), and about half of those live in or adjacent to this wetland as a result of increasing rural-urban migration from the civil conflict and in search for employment. The ecological integrity and biodiversity of the wetlands is and has been under severe pressure. The Mesurado River is reportedly the most polluted body of water in Liberia (e.g., petro-chemicals, sewage) (EPA 2007). Nevertheless, the wetland supports diverse animal and plant life (EPA 2007; Ramsar 2010).

Far southwest is Lake Shepherd (about 7,284 ha) in Maryland County, characterised by a mixed salt, brackish, and freshwater system (Wiles 2005; EPA 2007). The lake is actually a long narrow lagoon, <1 km wide, parallel to the coast (EPA 2007). Other major lagoons are Bernard Beach Lagoon, Montserrado County, the Sherman Lagoon, and Caesar Beach Lagoon (Wiles 2005). Another wetland is the Bafu Bay Wetland, a coastal mangrove wetland located in the southeast in Sinoe County, covers 4,816 ha and is situated along the Bafu River (EPA 2007).

The Gbedin Wetlands (about 4,532 ha, St. Johns River drainage) is another internationally well recognised and important wetland (Ramsar 2010) located in the northern highlands region of Liberia at about 1000 m elevation between the cities of Gahnpa (Ganta) and Sanniquellie, Nimba County. They receive about 1750-2250 mm of rainfall per year (Gatter 1997). The wetlands, consisting of a large swamp, as well as human-made paddies and irrigation channels, are important for swamp rice reproduction, as a migratory and resident bird feeding and resting area, and for supporting other endemic and imperilled vertebrates (EPA 2007; Ramsar 2010).

4.2 Climate rationale

Liberia is increasingly vulnerable to climate risks and climate-related hazards because of its low level of adaptive capacity, which emanated from the low level of human and institutional capacity, technology, infrastructure, finance, economy, etc. This has led to the severe impact of climate change on different priority sectors including agriculture and food security, health, energy, water resources, forestry and wildlife, coastal area, fishery, mining, industry, transport and tourism. In forest-dependent communities, climate change-induced extreme events are limiting the ability of communities to meet their basic requirements for food due to reduction in the amount of productive land and pest infestation of crops, lack of access to clean water, medicinal products, and fuelwood among other things, which they get from the forest.

The disruption to the agricultural system resulting from climate-induced changes in patterns of rainfall and temperature brings unhealthy implications for the country, where more than 70% of the population engage in agriculture as their main livelihood activity.

Sea-level rise induced flooding in Liberia is also an obvious and immediate threat to economic growth by affecting energy supply, disrupting roads and transport infrastructure as well as settlement as was recorded in 2007 and 2009. Also, the adverse effect of climate change has been exerting pressure on inland, coastal and marine aquatic resources as well as on energy accessibility and efficiency, industrial activity, transport infrastructure, wildlife, tourism, health and settlement and urbanisation.

It is therefore imperative to upscale existing hydro-meteorological systems to provide timely, accurate and actionable climate information for Liberia to effectively respond and adapt to climate risks. Thus, the proposed project will build on the just ended Early Warning System (EWS) project (2014 -2018) that sought to help Liberia realise her long term development planning benefit of a streamlined, customised and consolidated EWS informed by accurate climate information.

4.2.1 Climatology of Liberia

Liberia is a country on the West African coast. It is characterised by complex orographic terrains around the eastern part of the country (as shown in Figure 12). Sierra Leone borders it to its northwest, Guinea to its north, Cote d'Ivoire to its east, and the Atlantic Ocean to its south-southwest. She lies within latitudes 4-9^{o}N and longitudes 7-12^{o}W with a population of 4.38 million[5], which is expected to reach 6.26 million by 2038. The country remains vulnerable to the adverse impacts of climate change and variability after initial efforts to strengthen the country's capacity to provide climate information services through a functional hydro-meteorological services. This is because the Liberian hydro-meteorological services still grapple with limited capacity to observe, monitor, and forecast essential climate variables required to develop, generate and deliver relevant, accurate and timely climate information to guide individual, public, and private decision-making processes when faced with climate-related hazards.

[5] Liberia Institute for Statistics and Geo-Information Services (2008) National Population and Housing Census (2008)

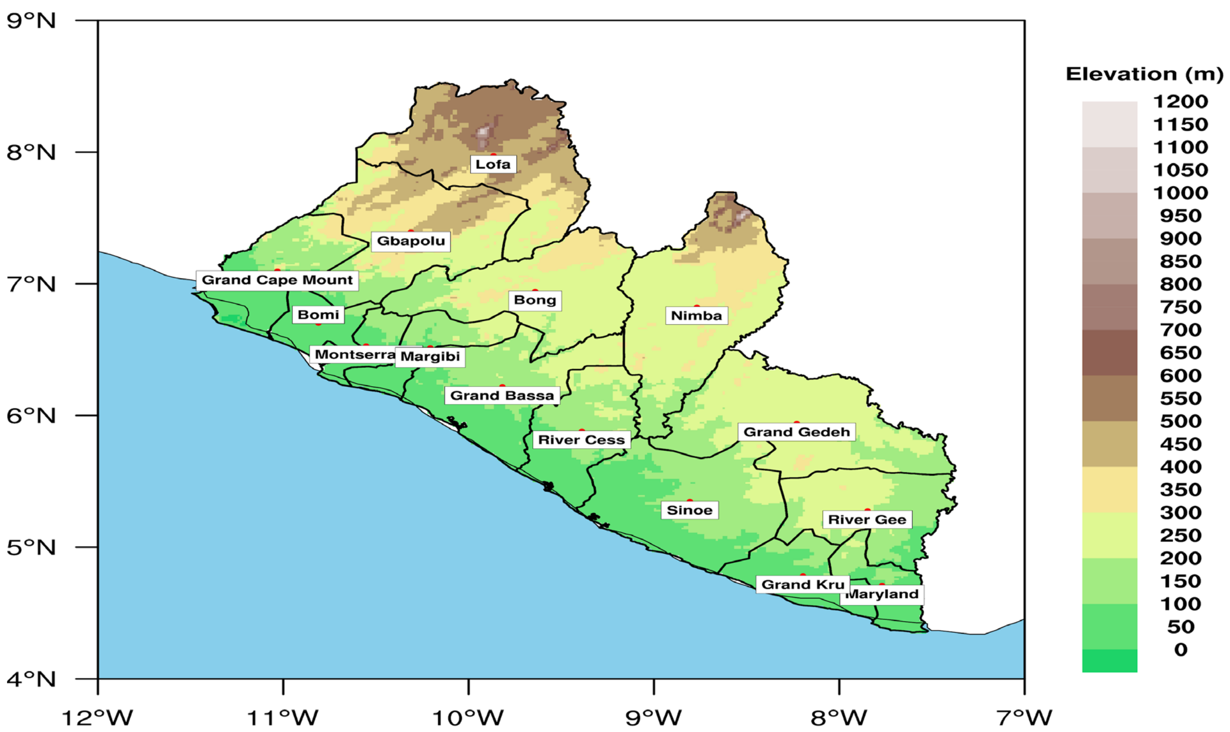


Figure 51: Map of Liberia showing elevation spaced at 50 meters interval

This situation undermines efforts across various sectors to understand the underlying climate science and acquire the related data needed to assess the past and current climate and to make future projections that should serve as the basis for inferring real and potential climate change and impacts on priority areas of national interest.

Liberia is a West African country where the climate is subject to considerable variability across a range of space and time scales (Lebel et al. 2000). This variability is linked to variations in the movement and intensity of the Inter-Tropical Convergence Zone (ITCZ) as well as variations in the timing and intensity of the West African Monsoon (WAM). The most documented cause of these variations on an inter-annual timescale is the El Niño Southern Oscillation (ENSO). The WAM is influenced either during the developing phase of ENSO or during the decay of some long-lasting La Niña events (Joly and Voldoire 2010). In general, El Niño (positive sea surface temperature anomalies in the equatorial Pacific Ocean) is connected to below normal rainfall in West Africa (Janicot et al. 1998). Other sources of variability at decadal, annual, and intra-seasonal time scales include land-atmosphere feedbacks (Taylor et al. 1997; Grodsky and Carton 2001; Douville 2002) and large-scale circulation features (Matthews 2004; Mournier et al. 2008; Lavender and Matthews 2009). At intra-seasonal time scales, the West African Monsoon system also exhibits variability, specifically at frequencies of 15 days and 25- 60 days (Janicot and Sultan 2001). The longer of these periods is associated with the Madden-Julian Oscillation - a major source of intra-seasonal variability in the tropical atmosphere with a period of 30-90 days, and variability in the Asian summer monsoon (Matthews 2004; Lavender and Matthews 2009; Janicot et al. 2009).

The exact location of the ITCZ varies considerably as the ITCZ over land tends to venture farther north or south than the ITCZ over the oceans due to the variation inland temperatures. In Africa, the northern extent of the ITCZ is just south of the Sahel at about 10-15° N. The southern progression of the ITCZ is limited by the WAM during winter (Figure 13).

The WAM is described as seasonal changes in surface winds usually accompanied by rainfall. The associated wind pattern is driven by differential heating of land and ocean. During the summer, the wind pattern shifts from the southwest, (warm and moist) to north-east (cold, dry and dusty) in the winter. During summer the southwest monsoon flow drives the ITCZ further north over West Africa, bringing rainfall to the Guinea Coast region. When the monsoon flow reverses during the winter, the northeast flow, referred to as the Harmattan Wind, is characterised as extremely dry and dust-laden.

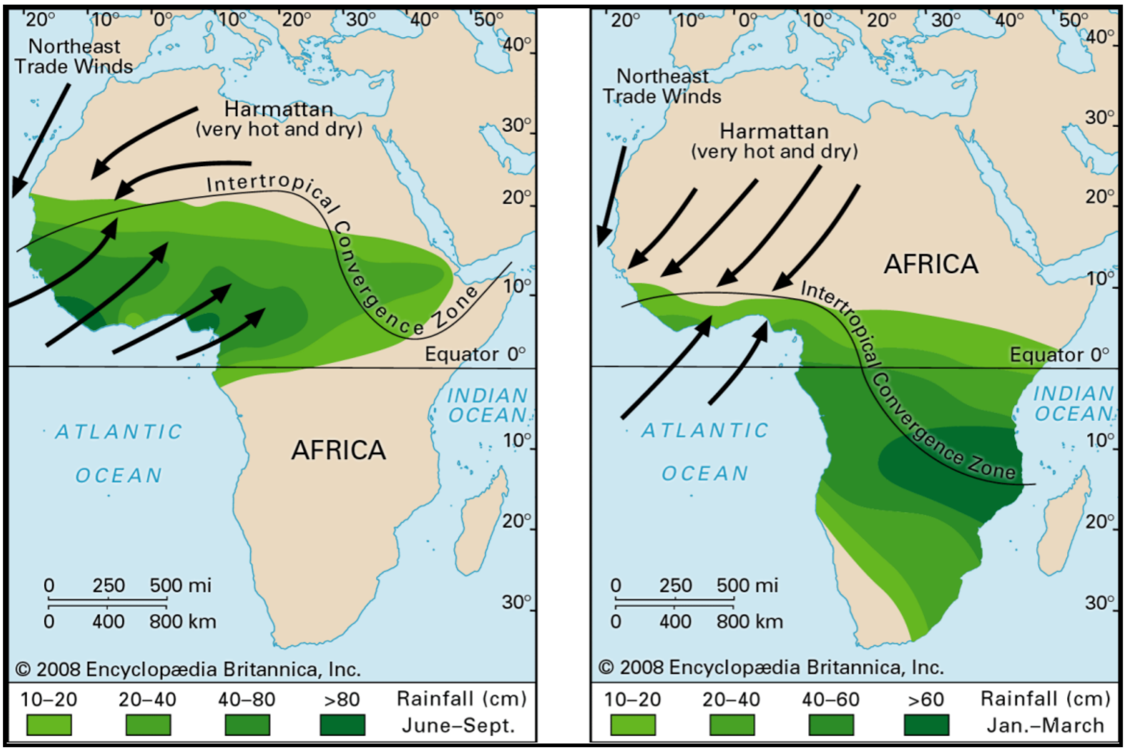


Figure 52: West African monsoon (https://www.britannica.com/science/West-African-monsoon; Accessed 29 January 2020)

The climate of Liberia is strongly influenced by the West African monsoon (WAM) system; a phenomenon defined as seasonal changes in surface winds usually accompanied by rainfall. The WAM provides over 70% of rainfall in the region[6]. Rainfall in Liberia is predominantly characterised by two weather seasons: dry and rainy[7]. The dry season commences from November through March, while the active rainy season spans from April through October (as shown in Figure 14).

[6] Hagos, S. M., & Cook, K. H. (2007). Dynamics of the West African monsoon jump. Journal of Climate, 20(21), 5264–5284. https://doi.org/10.1175/2007JCLI1533.1

[7]Liberia NAPA 2008. Liberia National Adaptation Programme for Action 2008.

The season of the year determines the temperatures in Liberia. Temperatures during the rainy season are relatively low because of near-complete cloud cover, and little diurnal variation in temperature occurs. Temperatures along the coast at this time of year are generally higher than inland as the southwesterly flow pushes the clouds inland, providing coastal regions with more solar radiation. In contrast, temperatures in the dry season, when cloud cover is minimal or nonexistent, are higher, and the diurnal range is much greater. Nights during the dry season can be cool, particularly when the Harmattan blows (Gatter 1997).

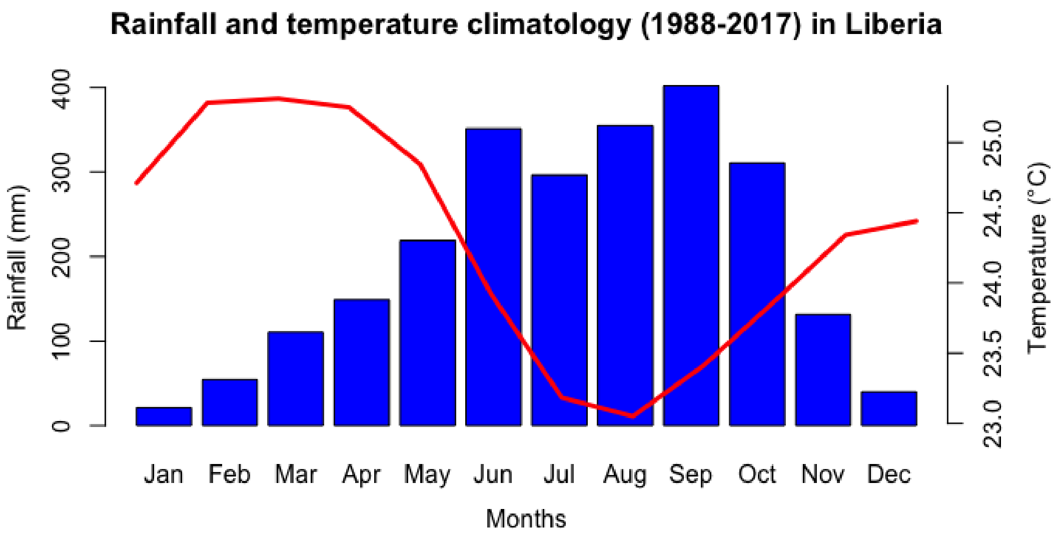


Figure 53: Rainfall and temperature climatology

Figure 14 shows the rainfall and temperature climatology for the period 1988-2017 (30years) and 1979-2017 (39years), respectively, in Liberia. The blue bar depicts the average monthly rainfall derived from Global Precipitation Climatology Centre (GPCC)[8] and the continuous red line depicts the 2meter surface temperature derived from ERA-Interim[9] dataset. From 1988 through 2017, temperatures typically ranged from 23 to 25° C during the wet season and 24 to 27° C during the dry season (as shown in Figure 10). These temperature ranges are consistent with those reported in previous studies (Coolidge, 1930; McSweeney et al., 2008), where values of 24 to 26° C and 24 to 29° C was found during the wet and dry seasons, respectively.

4.2.2 Historical Climate

---

[8] Schneider, Udo; Becker, Andreas; Finger, Peter; Meyer-Christoffer, Anja; Rudolf, Bruno; Ziese, Markus (2011): GPCC Full Data Reanalysis Version 6.0 at 0.5°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data. DOI: 10.5676/DWD_GPCC/FD_M_V7_050

[9] Dee, D.P., Uppala, S.M., Simmons, A.J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M.A., Balsamo, G., Bauer, D.P. and Bechtold, P., 2011. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. Quarterly Journal of the royal meteorological society, 137(656), pp.553-597.

4.2.2.1 Temperature Analysis

The surface temperature remains one of the critical essential climate variables that can be used to understand and describe the state of the climate system. The huge data gap and unavailable climate record in Liberia, however, limits historical climate assessments to the use of derived products from satellite, reanalysis and model products.

The temperature in Liberia is defined by its tropical location, where the sun is almost directly overhead all year (Gatter, 1997). Generally, the country experiences high temperatures all the time that show little variation. The temperature over the whole country ranges from 27-32° C during the day and from 21-24° C at night (MPEA, 1983). Average annual temperatures along the coast range from 24-30° C (MPEA, 1983). The temperature rises slightly in the dry season and decreases in July and August. Towards the interior of the country, the average maximum rises and the average minimum decreases. For example, temperatures during the hottest month of the dry season at Tappita, Nimba County, which is about 120 km from the coast, are 1.2° C higher than at Monrovia, and the coolest month of the rainy season is 2.0° C less than the average temperature on the coast at Monrovia, Montserrado County. Average annual temperatures are highest in the central belt of Liberia with temperatures in the interior averaging between 27-32° C (MPEA, 1983). At the Nimba and Wologizi mountain ranges in the interior, the height above sea level (ca. 700-1400 m) results in a lowering of the maximum temperature.

The climate models are the only primary tools available to investigate the response of the climate system to different forcings for future climate projections and predictions (Flato et al., 2013). It is therefore paramount to evaluate the performance of these models, either objectively or probabilistically, to increase the confidence on inferences made from outputs of future climate runs.

Figure 15 presents the spatial distribution of observed and modelled averaged annual surface temperature for the period 1976-2005 in Liberia. Figure 15 shows that spatial temperature varies between 22.5 to 27 ^{o}C across the country. Though there exists a notable spatial difference of about 1 ^{o}C or less between the observed and modelled values, the distribution displays a similar pattern of decreasing values from the vast coastline towards the eastern part of the country. These characteristics indicate that low-lands, most especially in areas near the coast, are warmer than highlands. The agreement between the observed and modelled values is expected because temperature decreases with height within the troposphere, the lowest part of the atmosphere. Also, Figure 15b shows that the model is sensitive to the topography (shown in Figure 12) of the country. Therefore, the model ensemble projections can serve as a useful source of information on the possible climate change signals to adduce potential risk and likely impacts on the country's priority sectors.

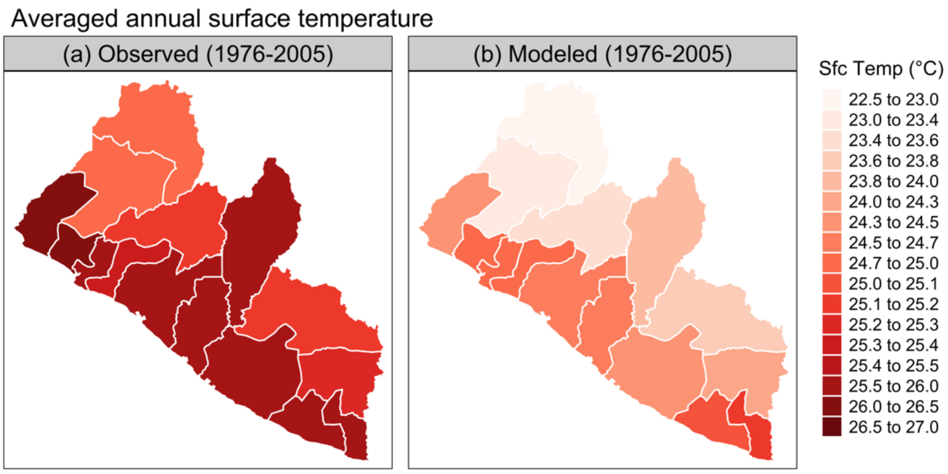


Figure 54: Spatial distribution of observed and modelled averaged annual surface temperature for the period 1976-2005 in Liberia.

4.2.2.2 Rainfall Analysis

Rainfall is one of the most important essential climate variables that can also be used to describe changes and variability in the climate system. This variable directly affects humans and economic activities through its duration, intensity and frequency or its lack of occurrence. Also, rainfall influences water supply causes risks to life and livelihoods when associated with floods, landslides, and droughts, and affects infrastructure planning, leisure activities and other related activities.
Given this numerous importance of rainfall, it is, however, crucial to analyse the variable to gain insight into the potential future changes and associated risks in Liberia.

The moisture-laden WAM winds from the southwest strike the Liberian coast head-on, increasing coastal rainfall despite the gradually increasing elevation inland. The average annual rainfall in the coastal belt could reach 4000 mm with individual months receiving more than 1000 mm of rainfall (McSweeney et al. 2008). Isohyets are essentially parallel to the coast in the central and eastern provinces. In western Liberia, the isohyets penetrate much deeper into the interior as the northeast-southwest alignment of the high mountain ranges channels the monsoon flow and prolongs the rainy season. Where the monsoon winds meet high coastal promontories (e.g., Cape Mount, Monrovia), the annual rainfall is much higher than average for the coastal region (Gatter 1997).

To evaluate the model ensemble performs against observations, similar to what was done for temperature, the spatial distribution of observed and modelled rainfall for the period 1976-2005 is presented in Figure 16. The average observed and modelled rainfall during the considered period is about 2445 mm and 2782 mm, respectively. Though the simulated rainfall is higher relative to the observed values, there is, however, a good agreement with the spatial distribution pattern in terms of higher values along the vast coastline and less inland.
One of the reasons for higher rainfall values along the coastal region can be explained by the nearly right-angle orientation of the coast. This feature causes the moisture-laden air masses from the West Coast to rise and then condense to form a cloud that favours the production of heavy rainfall. Another reason can be tied to the increase in evaporation because of higher surface temperature around the coastal zones that enhances localised rainfall.

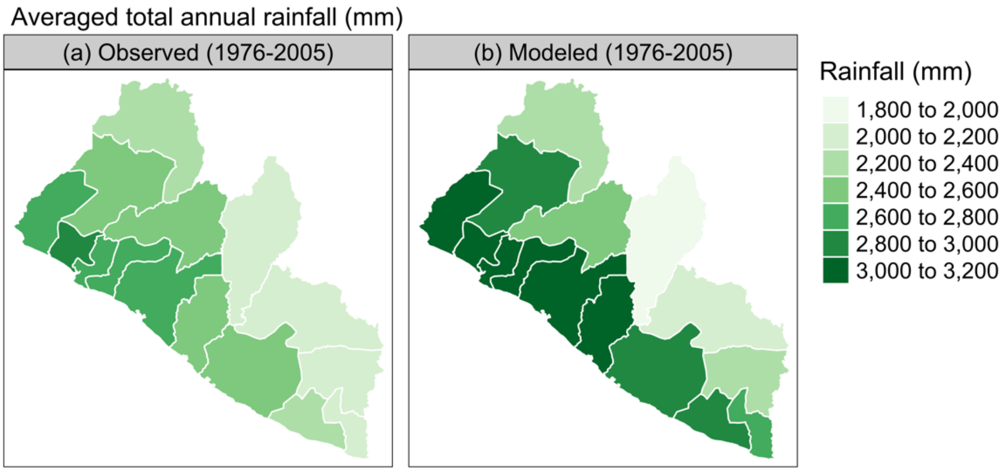


Figure 55: Spatial distribution of observed and modelled rainfall for the period 1976-2005

4.2.2.3 Relative Humidity Analysis

The relative humidity is generally high overall of Liberia due to its nearness to the coast. Along the immediate coast, humidity levels rarely drop <80% and averages >90%. Much wider variation in humidity occurs in the interior, particularly during the dry season as the Harmattan may drop humidity levels to <20% (Gatter, 1997). The variation in this variable contributes to the average annual rainfall in the coastal belt, which can reach 4000 mm with individual months receiving >1000 mm of rainfall (McSweeney et al., 2010). Isohyets are essentially parallel to the coast in the central and eastern provinces. A similar pattern occurs in Sierra Leone to the west. In western Liberia, the isohyets penetrate much deeper into the interior as the northeast- southwest alignment of the high mountain ranges channels the monsoon flow and prolongs the rainy season. Where the monsoon winds meet high coastal promontories (e.g., Cape Mount, Monrovia), the annual rainfall is much higher than the average for the coastal region (Gatter, 1997).

4.2.3 Future projections

4.2.3.1 Methodology 1: Climate Assessment using the approach proposed in the IPCC SRES

A climate projection study documented in a USAID (2013) report applied climate modelling in four ways: (i.) ensemble projections, (ii) statistical downscaling, (iii) dynamic downscaling, and (iv) a constructed aridity index for examining the effects of climate change on social and natural systems.

Global Circulation Models (GCMs) are useful tools to assess the mean state of the global climate system. However, most GCMs have difficulty correctly reproducing several key features of the atmospheric circulation patterns over West Africa, contributing to the uncertainty in estimates of future rainfall (Annamalai et al. 2007; Caminade and Terray, 2010; Douville et al., 2006; Joly et al., 2007). Due to this shortfalls, the analysis focus on the changes predicted by an ensemble of climate models because this provides a means of examining not only the projected change in temperature and precipitation but also avoids results that are dependent upon a single model. The first set of projections of potential changes in temperature and precipitation presented are the result of averaging

16 atmosphere-oceans general circulation models (AOGCMs)10 that were downscaled to a horizontal grid size of about 50 km following the statistical methodology described in Maurer et al. (2009). The use of an ensemble of models helps limit the influence of any bias present in any one model. The analysis focused on three areas: coastal (Monrovia), inland (Nimba), and southern (Sapo National Park).

Projecting future climatic conditions requires that assumptions be made about how the human component of the climate system will evolve throughout the forecast period. This is typically accomplished by developing different scenarios of anthropogenic influences, basically different rates of greenhouse gas emissions. These scenarios do not represent predictions but are instead alternative views of how the future may unfold. The Intergovernmental Panel on Climate Change (IPCC) developed four different families of scenarios in the Special Report on Emission Scenarios (SRES). Three of those families described in various IPCC documents (IPCC, 2007) are used here.

- A2 - The A2 storyline and scenario family describe a heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge slowly, which results in high population growth. Economic development is primarily regionally oriented, and per capita, economic growth and technological changes are more fragmented and slower than in other storylines.

- A1B1 - The A1 storyline and scenario family describes a future world of rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system.

- B1 - The B1 storyline and scenario family describe a convergent world with the same low population growth as in the A1 storyline but with rapid changes in economic structures toward a service and information economy with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

Modelled temperature and precipitation for the three emission scenarios were analyzed and report of the ensemble averages for each scenario, as well as standard deviation, maximum and minimum values, and the means across the scenarios, are presented.

i. Ensemble Projections for Representative Areas

Projected changes in temperature and precipitation by 2050 and 2080 for Monrovia, Nimba, and Sapo National Park are based on an ensemble of 16 AOGCMs (Tables 9-11). The most conservative estimates on temperature change (scenario B1) have

[10] For this we downscaled GCM output from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007) as described by Maurer et al. (2009) using the bias-correction/spatial- downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of (Adam and Lettenmaier, 2003). Temperature and precipitation data are available from http://www.climatewizard.org.

Monrovia warming by an estimated average of 1.54°C by 2050 and 1.90°C by 2080 during the dry season (1.30°C by 2050 and 1.85°C by 2080 for the wet season). In the interior, Nimba is estimated to warm by an average of 1.50°C by 2050 and 2.13°C by 2080 during the dry season (1.38°C by 2050 and 1.82°C by 2080 for the wet season). In the southeast, Sapo National Park is projected to warm slightly less, by an estimated average of 1.44°C by 2050 and 1.95°C by 2080 during the dry season (1.29°C by 2050 and 1.73°C by 2080 for the wet season).

Perhaps the best estimate of the impact of future climate conditions on temperature is provided by the overall ensemble mean of 16 climate models across three emission scenarios (Tables 9-11) which suggests that Monrovia will warm by 1.92 ± 0.65°C by 2050 and 2.65 ± 0.84°C by 2080 during the dry season (1.61 ± 0.35°C by 2050 and 2.60 ± 0.79°C by 2080 during the wet season). Nimba will warm by 1.87 ± 0.61°C by 2050 and 2.99 ± 1.04°C by 2080 during the dry season (1.71 ± 0.41°C by 2050 and 2.56 ± 0.76°C by 2080 during the wet season). Sapo National Park will warm by 1.77 ± 0.56°C by 2050 and 2.73 ± 0.90°C by 2080 during the dry season (1.61 ± 0.35°C by 2050 and 2.43 ± 0.69°C by 2080 during the wet season). Regardless of the emission scenario, the AOGCMs are quite consistent in predicting warmer conditions throughout Liberia.

The study shows that AOGCM predictions of precipitation in Liberia are not consistent. Forecast changes in precipitation in Monrovia range from 36% decrease to 21% increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight increase in wet season rainfall of 1.54 ± 11.09% by 2050 and 1.92 ± 13.21% by 2080. In Nimba, forecast changes in precipitation range from 40% decrease to 24% increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a negligible change in wet season rainfall of 0.35 ± 10.28% by 2050 and 0.40 ± 13.67% by 2080. At Sapo National Park, forecast changes in precipitation range from 40% decreases to 35% increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight increase in wet season rainfall of 3.54 ± 11.55% by 2050 and 5.25 ± 16.26% by 2080.

Table 9: Potential change in temperature (oC) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun- Aug) seasons at Monrovia (Source USAID 2013).

Monrovia		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.54**	**2.15**	**2.07**	**1.92**	**1.30**	**1.79**	**1.75**	**1.61**
	Std Dev	0.48	0.53	0.77	0.65	0.29	0.28	0.27	0.35
	Min	0.50	0.91	-0.07	-0.07	0.62	1.26	1.13	0.62
	Max	2.19	3.02	3.19	3.19	1.76	2.30	2.14	2.30
2080 Temperature	Mean	**1.90**	**2.83**	**3.22**	**2.65**	**1.85**	**2.75**	**3.21**	**2.60**
	Std Dev	0.47	0.57	0.81	0.84	0.45	0.56	0.63	0.79
	Min	1.10	1.91	1.26	1.10	0.80	1.57	1.85	0.80
	Max	2.68	3.81	4.77	4.77	2.75	4.01	4.35	4.35
2050 Precipitation	Mean	**0.63**	**6.31**	**3.94**	**3.63**	**0.88**	**1.50**	**2.25**	**1.54**
	Std Dev	-5.50	1.00	-2.00	-1.50	10.28	11.79	11.81	11.09
	Min	-22.00	-26.00	-24.00	-26.00	-26.00	-25.00	-25.00	-26.00
	Max	20.22	24.40	28.55	24.21	16.00	20.00	20.00	20.00
2080 Precipitation	Mean	**6.13**	**6.50**	**11.13**	**7.92**	**3.13**	**1.94**	**0.69**	**1.92**
	Std Dev	23.10	31.49	40.49	31.86	11.52	14.20	14.46	13.21
	Min	-25.00	-47.00	-35.00	-47.00	-29.00	-36.00	-32.00	-36.00
	Max	55.00	92.00	125.00	125.00	18.00	18.00	21.00	21.00

Table 10: Potential changes in temperature (oC) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Nimba (Source USAID 2013).

Nimba		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.50**	**2.08**	**2.02**	**1.87**	**1.38**	**1.91**	**1.85**	**1.71**
	Std Dev	0.45	0.49	0.71	0.61	0.33	0.35	0.33	0.41
	Min	0.56	0.94	0.03	0.03	0.69	1.27	1.15	0.69
	Max	2.07	2.95	3.02	3.02	1.97	2.52	2.40	2.52
2080 Temperature	Mean	**2.13**	**3.18**	**3.65**	**2.99**	**1.82**	**2.70**	**3.16**	**2.56**
	Std Dev	0.57	0.73	1.12	1.04	0.43	0.54	0.60	0.76
	Min	1.21	2.03	0.67	0.67	0.79	1.55	1.83	0.79
	Max	3.14	4.52	5.39	5.39	2.66	3.86	4.24	4.24
2050 Precipitation	Mean	**0.06**	**5.88**	**5.69**	**3.88**	**-0.31**	**0.56**	**0.81**	**0.35**
	Std Dev	15.40	22.38	22.71	20.19	9.74	10.88	10.81	10.28
	Min	-25.00	-29.00	-22.00	-29.00	-22.00	-21.00	-22.00	-22.00
	Max	36.00	46.00	62.00	62.00	11.00	15.00	14.00	15.00
2080 Precipitation	Mean	**9.81**	**9.75**	**13.25**	**10.94**	**2.31**	**0.63**	**-1.75**	**0.40**
	Std Dev	20.39	35.43	32.21	29.45	11.76	15.26	14.34	13.67
	Min	-21.00	-44.00	-31.00	-44.00	-29.00	-40.00	-32.00	-40.00
	Max	47.00	83.00	73.00	83.00	17.00	24.00	18.00	24.00

Table 11: Potential change in temperature (oC) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun- Aug) seasons at Sapo National Park (Source USAID 2013).

Sapo National Park		Dry Season				Wet Season			
		B1	A1B	A2	Mean	B1	A1B	A2	Mean
2050 Temperature	Mean	**1.44**	**1.97**	**1.91**	**1.77**	**1.29**	**1.78**	**1.74**	**1.61**
	Std Dev	0.41	0.46	0.65	0.56	0.28	0.28	0.28	0.35
	Min	0.60	0.98	0.12	0.12	0.66	1.22	1.10	0.66
	Max	2.00	2.77	2.73	2.77	1.70	2.29	2.13	2.29
2080 Temperature	Mean	**1.95**	**2.92**	**3.32**	**2.73**	**1.73**	**2.56**	**2.99**	**2.43**
	Std Dev	0.49	0.60	0.92	0.90	0.39	0.45	0.51	0.69
	Min	1.17	1.98	1.02	1.02	0.77	1.48	1.77	0.77
	Max	2.80	3.81	4.90	4.90	2.36	3.38	4.01	4.01
2050 Precipitation	Mean	**1.38**	**4.69**	**3.50**	**3.19**	**2.50**	**4.19**	**3.94**	**3.54**
	Std Dev	0.00	2.00	0.50	0.00	10.33	12.94	11.92	11.55
	Min	-15.00	-18.00	-16.00	-18.00	-18.00	-22.00	-18.00	-22.00
	Max	11.94	14.76	15.05	13.76	16.00	25.00	26.00	26.00
2080 Precipitation	Mean	**6.81**	**7.13**	**7.88**	**7.27**	**7.13**	**5.81**	**2.81**	**5.25**
	Std Dev	15.35	23.78	19.01	19.27	12.60	17.87	18.42	16.26
	Min	-19.00	-34.00	-26.00	-34.00	-25.00	-31.00	-40.00	-40.00
	Max	47.00	72.00	50.00	72.00	21.00	29.00	35.00	35.00

ii. Statistical Downscaling

To examine the spatial pattern of the potential changes of precipitation, the output from the National Centre for Atmospheric Research (NCAR) Community Climate Model version 3 (CCM3) that was statistically downscaled to a 1-km resolution following the methodology of (Hijmans et al., 2005). The CCM3 was used because of its response for the A1B scenario agreed well with the overall ensemble mean (across all emission scenarios). Historical weather data from WMO meteorological stations in the surrounding countries were used in the statistical downscaling.

The spatial pattern of temperature change is also presented using the mean high and low daily temperatures (Figure 17). This show that changes in high temperatures will be less than 2°C throughout the country, but average low temperatures (i.e., nighttime temperatures) will increase more than 2°C in the interior. Comparing current with 2050 projections of average maximum temperature in February, generally, the hottest month (Figure 18), shows a 1°-2° C increase throughout most of the country with the highest temperature approaching 36° C in the interior. For the same month, the comparison of current to projected 2050 average low temperatures indicates a 2° C increase in nighttime temperature along the coast in the west and the northeastern border area (Figure 19).

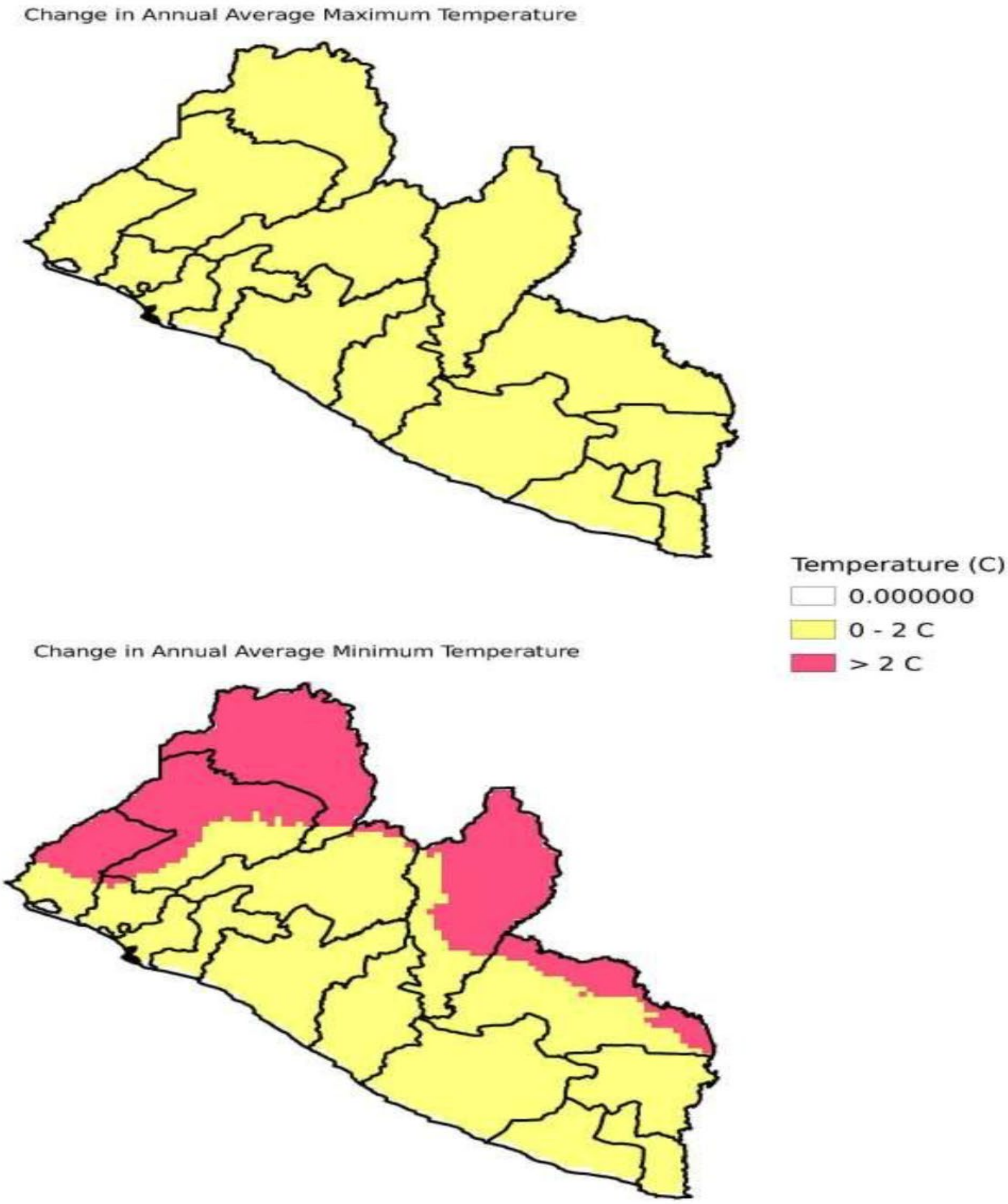


Figure 56: Change in average annual maximum and minimum temperatures, current vs 2050. (Source USAID 2013)

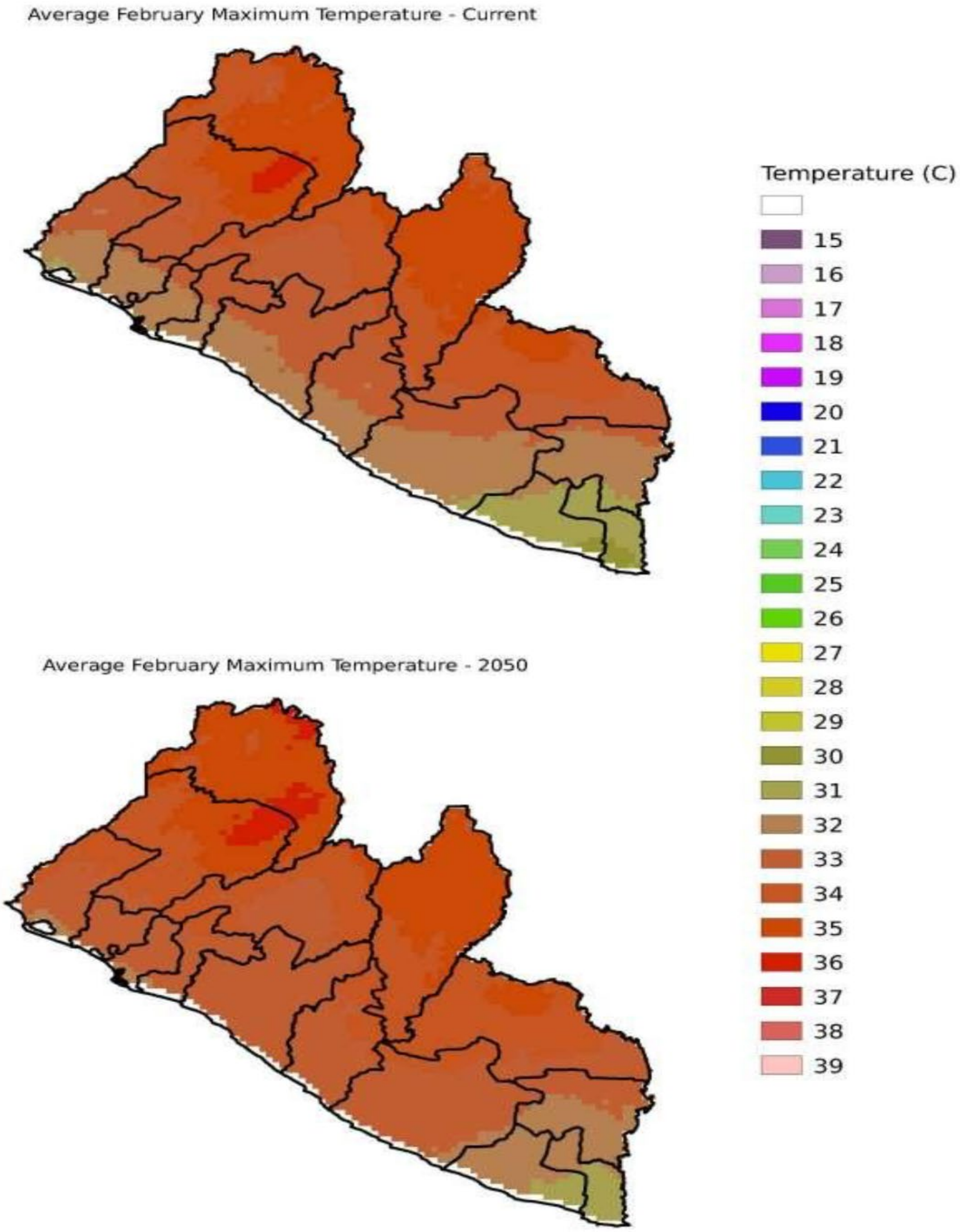


Figure 57: Average daily maximum temperature in February, current vs 2050 (Source USAID 2013).

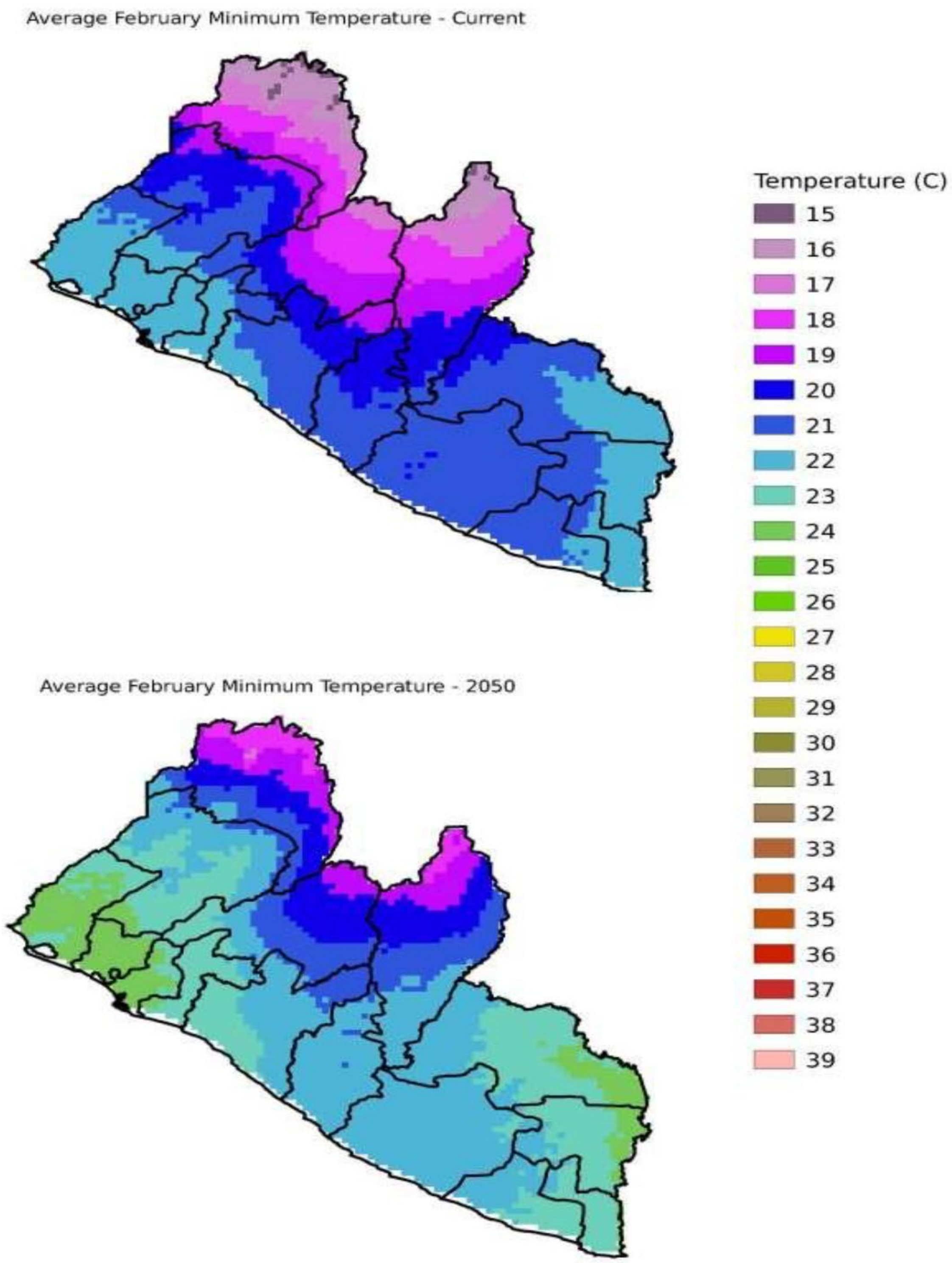


Figure 58: Average daily minimum temperature in February, current vs 2050 (Source USAID 2013).

According to the USAID (2013) study on climate change assessment, the spatial pattern of average annual precipitation currently versus 2050 (Figure 20) shows slight increases in total rainfall with the rainfall bands widening inland in the future. The greatest average annual precipitation of about 5,000 mm in 2050 is projected along the western coast. During the wet season (May to August, Figs. 21-24) the expected increase in rainfall will likely be focused along the coast with inland regions experiencing normal to slightly reduced rainfall. The increased rainfall appears to occur mostly during the early months of the rainy season, beginning in the southeast in May and extending west along the coast in June and July, implying more intense rainfall events. By 2050 warmer ocean conditions result in a weaker initial monsoon flow in May, allowing drier conditions induced by northeasterly flow to persist longer in the northern half of Liberia. May rainfall along the coast of the southern half is enhanced. June brings a stronger monsoon flow enhancing coastal rainfall amounts and pushing rains farther inland relative to current conditions. A small pocket of dry conditions persists in the northern interior (Figure 21). July brings the start of the mid-day period.

Although the general pattern for the mid-dries appears similar in Liberia for the current and 2050 comparisons, an area of dryness to the east expands dramatically. Coastal rainfall in the northern half of Liberia continues above current levels. There is little change for coastal Liberia in the pattern of August rainfall, but conditions are slightly drier than current for the northern part of the country, implying a shift in the pattern of the rainy season. Since these projections result from a statistical downscaling process, it is important to note that such a technique tends to impose current patterns of spatial variability upon future conditions. These projections are consistent with a warmer tropical Atlantic Ocean, which reduces the land-sea temperature contrast that drives the monsoon system. A reduced land-sea contrast weakens the monsoon flow that limits the inland penetration of the moisture-laden marine air mass, thus reducing rainfall in the interior.

Because of the complexity of correctly reproducing several key features of the atmospheric circulation patterns over West Africa, projections of rainfall by climate models are mixed and uncertain. Our ensemble modelling projections of rainfall among three representative meteorological stations also gave mixed and inconclusive results, lacking consistency and predicting decreases and increases in rainfall across stations. With the warming projected, an increase in rainfall is the most likely outcome from a dynamic perspective. In general, abundant monsoonal rainfall is consistent with warmer tropical Atlantic sea surface temperatures as they enhance latent heat fluxes from the ocean to the atmosphere.

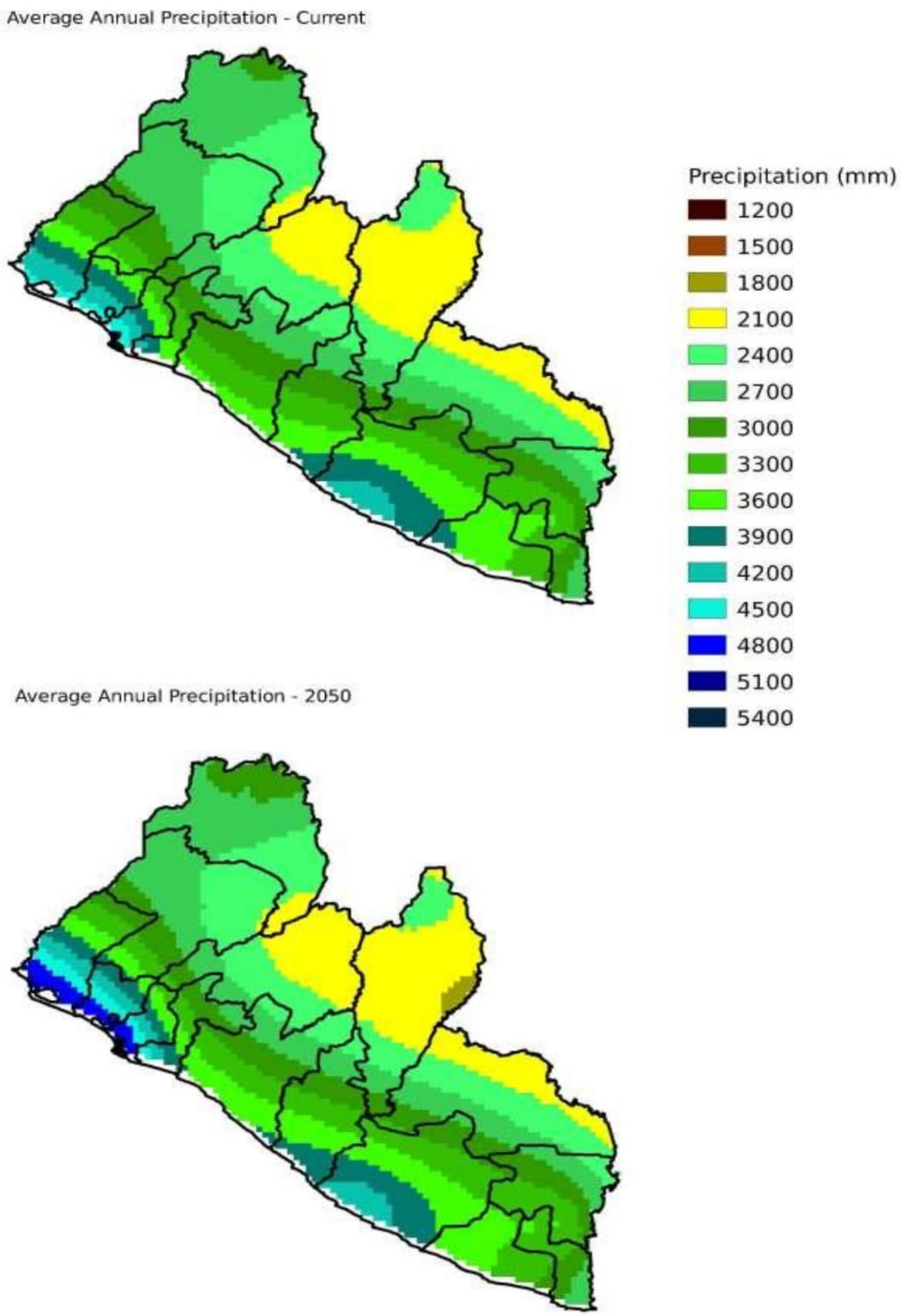


Figure 59: Average annual precipitation, current vs 2050 (Source USAID 2013).

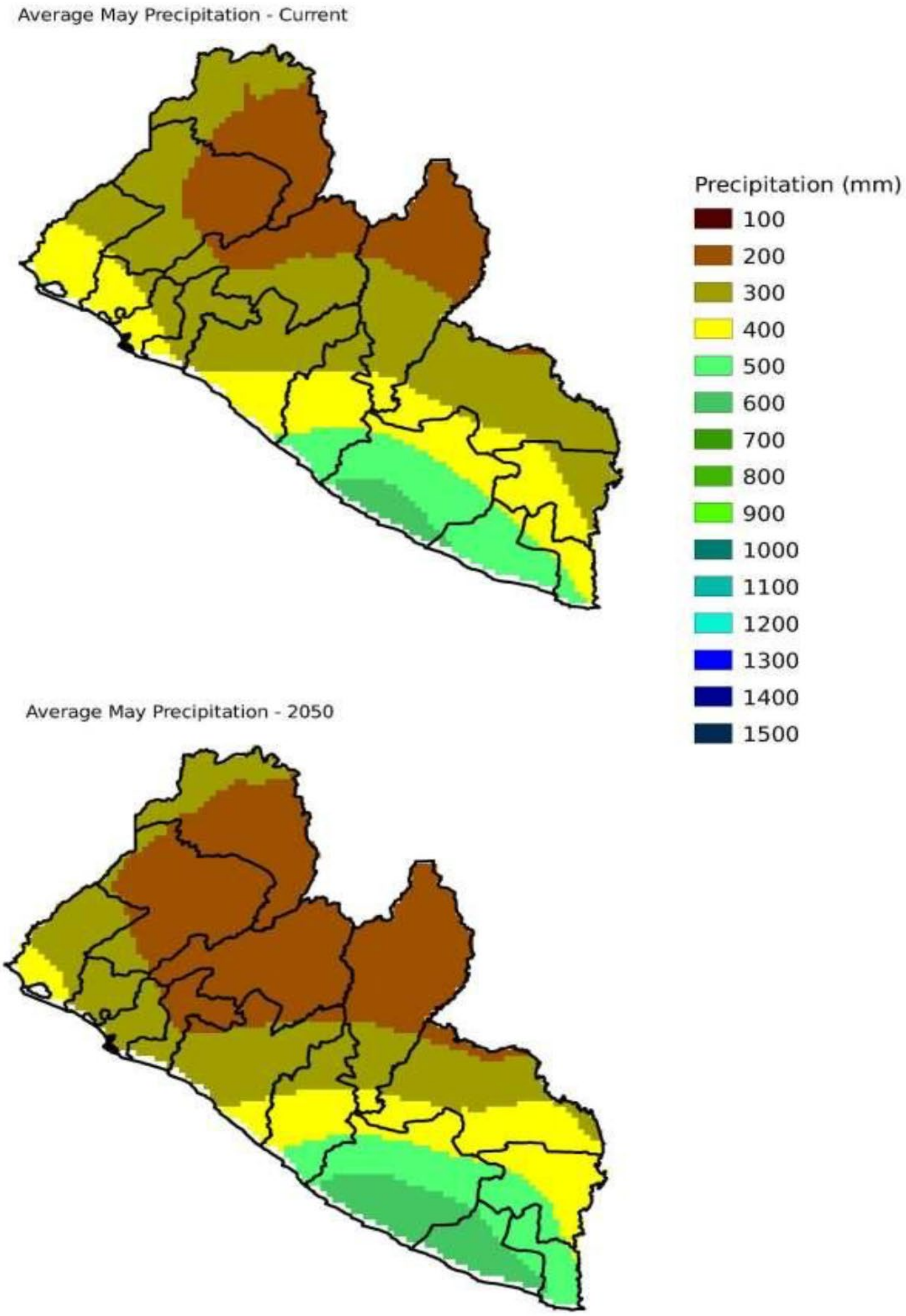


Figure 60: May (wet season) average monthly precipitation, current vs 2050 (Source USAID 2013).

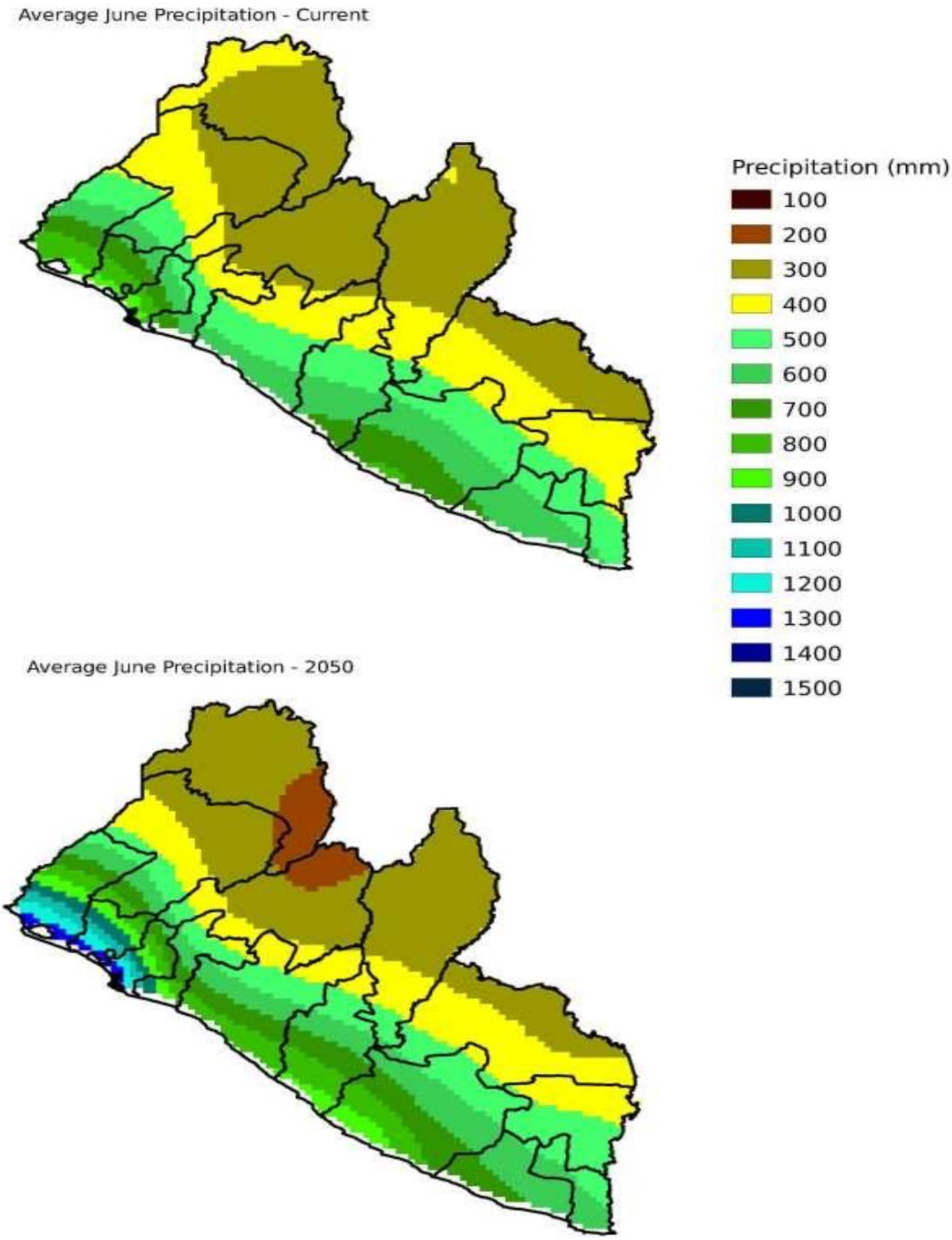


Figure 61: June (wet season) average monthly precipitation, current vs 2050 (Source USAID 2013).

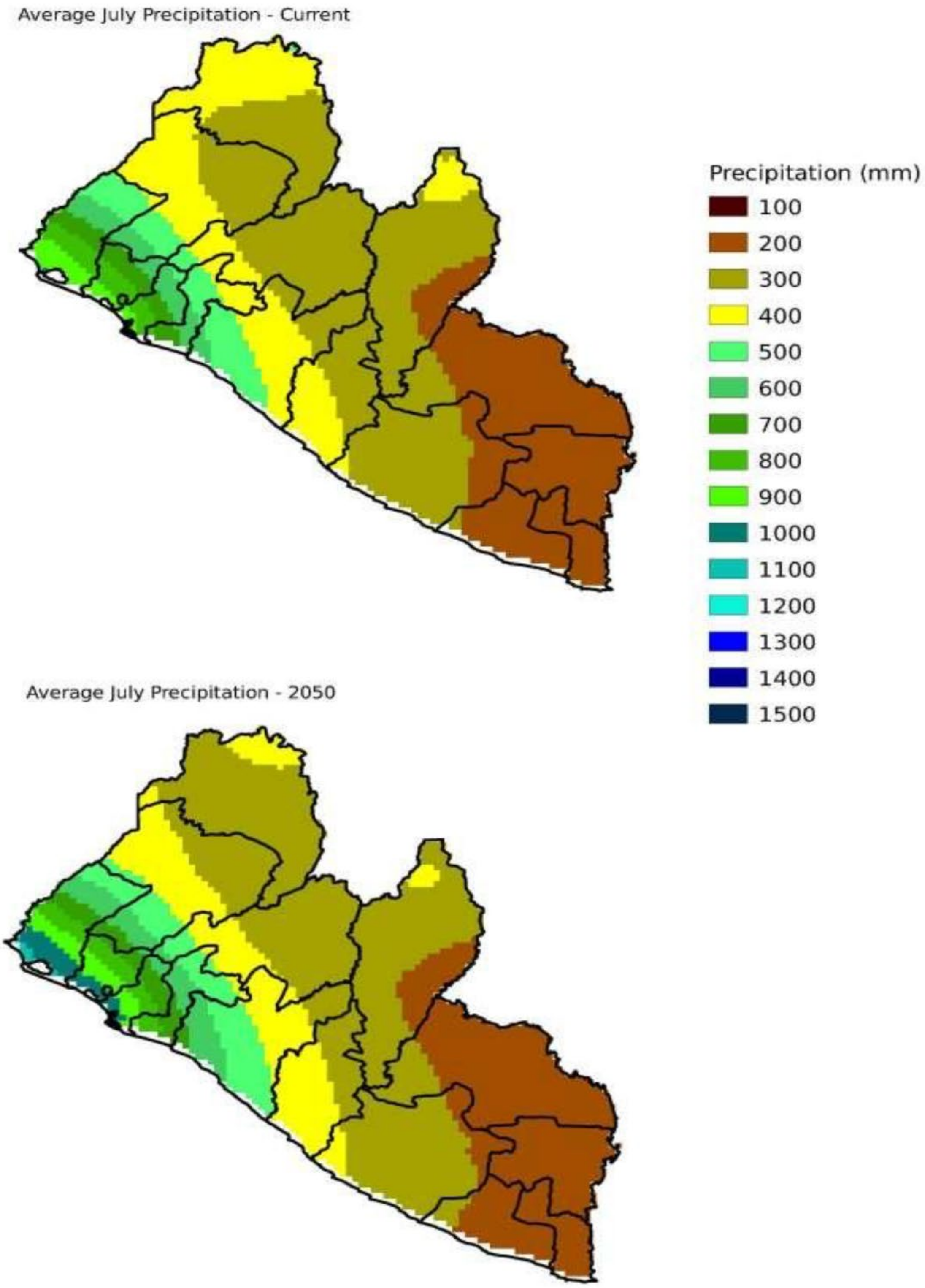


Figure 62: July (wet season) average monthly precipitation, current vs 2050 (Source USAID 2013).

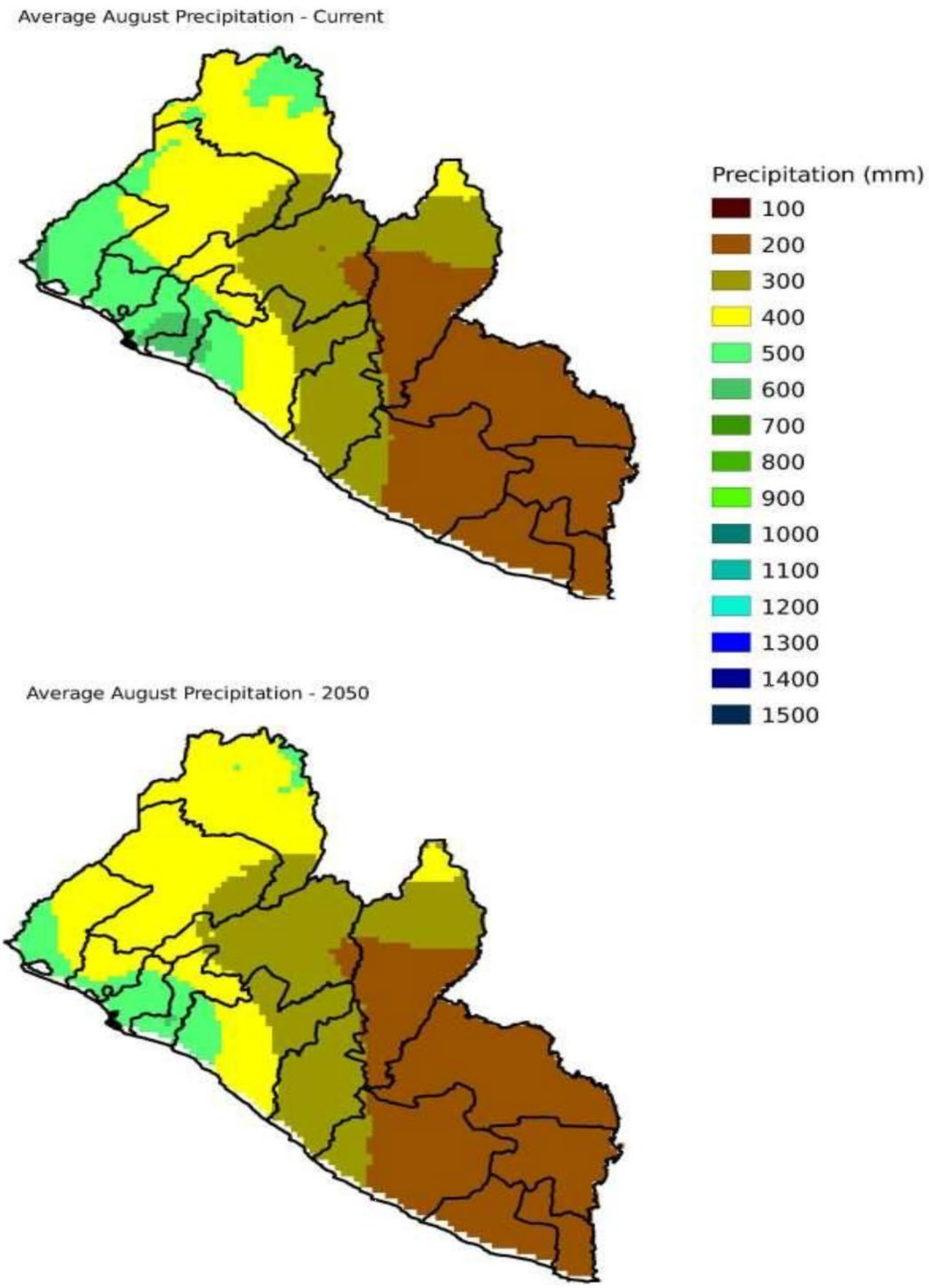


Figure 63: August (wet season) average monthly precipitation, current vs 2050 (Source USAID 2013).

iii. Dynamic Downscaling

Dynamic downscaling is a numerical method of nesting a higher resolution model within the GCM domain. The primary advantage gained using a high-resolution model is that the spatial properties of the data are determined by atmospheric physics and not an arbitrary interpolation method. The benefit of using a regional climate model (RCM) is to provide a more detailed representation of the important atmospheric processes contributing to climate variations. It is, however, important to note that a major challenge with RCMs is with setting up the numerous parameters available within the model that control convection, land-surface interactions and other subgrid-scale processes. Variations in these parameters can result in significant differences in model results. It is quite important to note that the analysis presented here is not an exhaustive evaluation of the model's input parameter space due to the high computational requirements for such a study. This is also why only one future emissions scenario was considered (A1B). The purpose of investigating the dynamically downscaled climate information is to examine the spatial patterns of change and how these patterns differ from those produced by the statistical downscaling.

Statistical projections of February average maximum temperatures indicated an increase of 1°-2° C increase throughout most of the country. Results from the dynamic downscaling indicate slightly stronger warming of just over 3° C along a band paralleling the coast (Figure 25). Average minimum temperatures for February did not show any significant warming which is in sharp contrast to the 2° C increase in nighttime temperature along the coast in the west and the northeastern border area found with the statistical downscaling (Figure 26). Warming at night is a characteristic of the greenhouse effect as the increased CO_2 helps reduce the amount of longwave radiation lost to space at night, resulting in a warming of the lower atmosphere. The lack of a warming signal in the nighttime temperatures for the dynamically downscaled projection is potentially tied to the difference in time frames being considered. The statistical downscaling was projected out through 2050; for the dynamical case, the projection year was 2030.

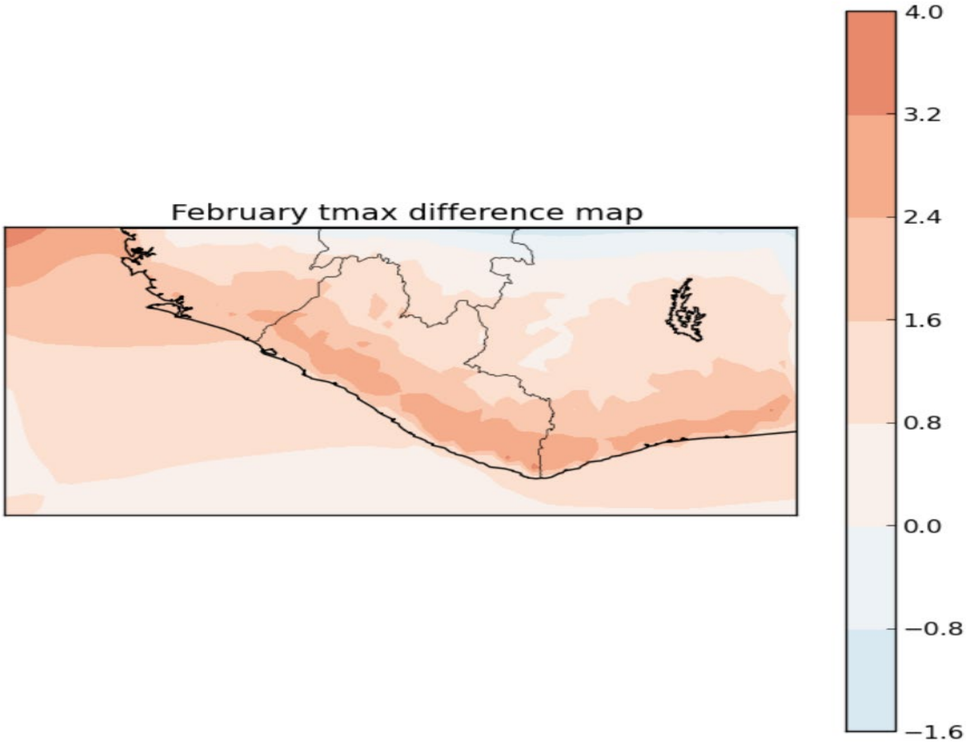


Figure 64: Change in February average maximum temperature for dynamic downscaling (° C) (Source USAID 2013).

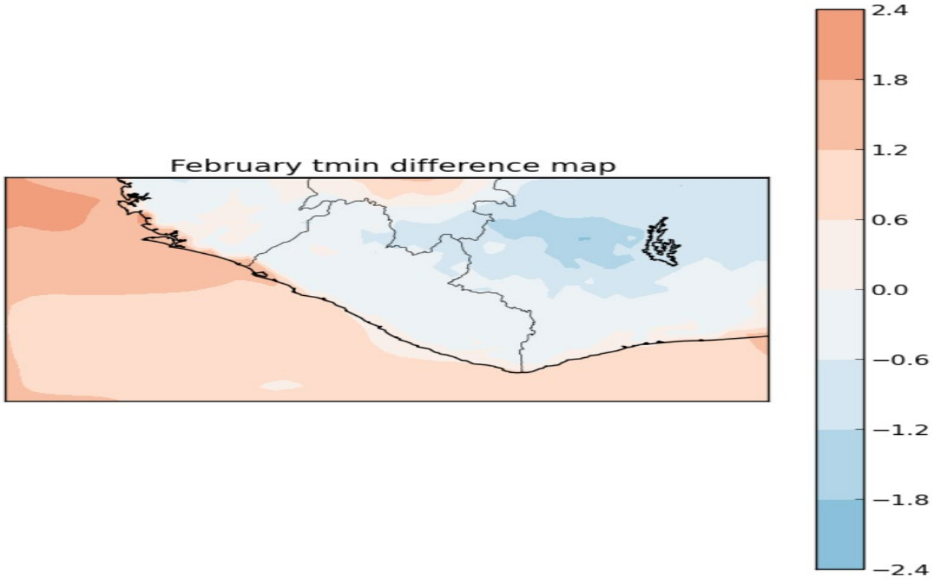


Figure 65: Change in February average minimum temperature for dynamic downscaling (º C) (Source USAID 2013).

The study reported increases rainfall focused along the coast with inland regions experiencing normal to slightly reduced rainfall from the statistically downscaled output during the wet season (May to August). The dynamic downscaling produces a slight reduction in precipitation in May (< 50 mm change) across much of the northern half of Liberia with little change elsewhere (Figure 27). Weaker initial monsoon flow in May paves the way for drier conditions induced by northeasterly flow to persist longer in the northern half of Liberia. May rainfall along the coast of the southern half is enhanced. June brings a stronger monsoon flow enhancing coastal rainfall amounts and pushing rains farther inland relative to current conditions. A small area of dry conditions persists in the northern interior (Figure 19). July brings the start of the mid-day period.

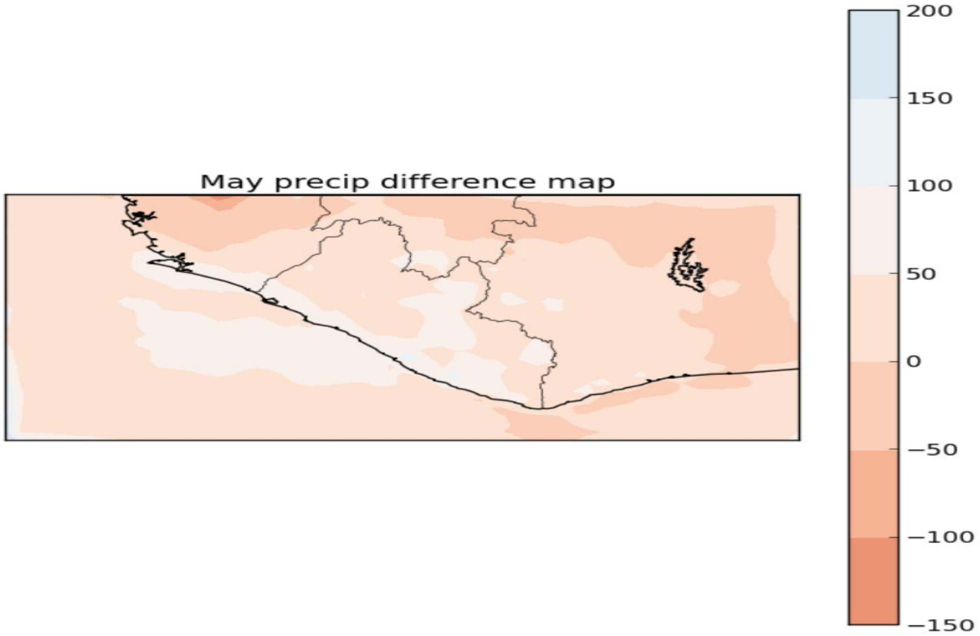


Figure 66: Dynamically downscaled change in precipitation for May (mm) (Source USAID 2013).

By June in the dynamically downscaled case, precipitation has begun to increase across much of the country (Figure 28). The slightly drier conditions in May followed by wetter conditions in June could be as a result of the northward shift in the mean position of the ITCZ, which allows inflow of moisture-laden air into the country. July continues to show enhanced precipitation across much of the country (Figure 29) and does not indicate the presence of a mid-dry period. Elevated precipitation levels persist through August as well in the dynamically downscaled case (Figure 30).

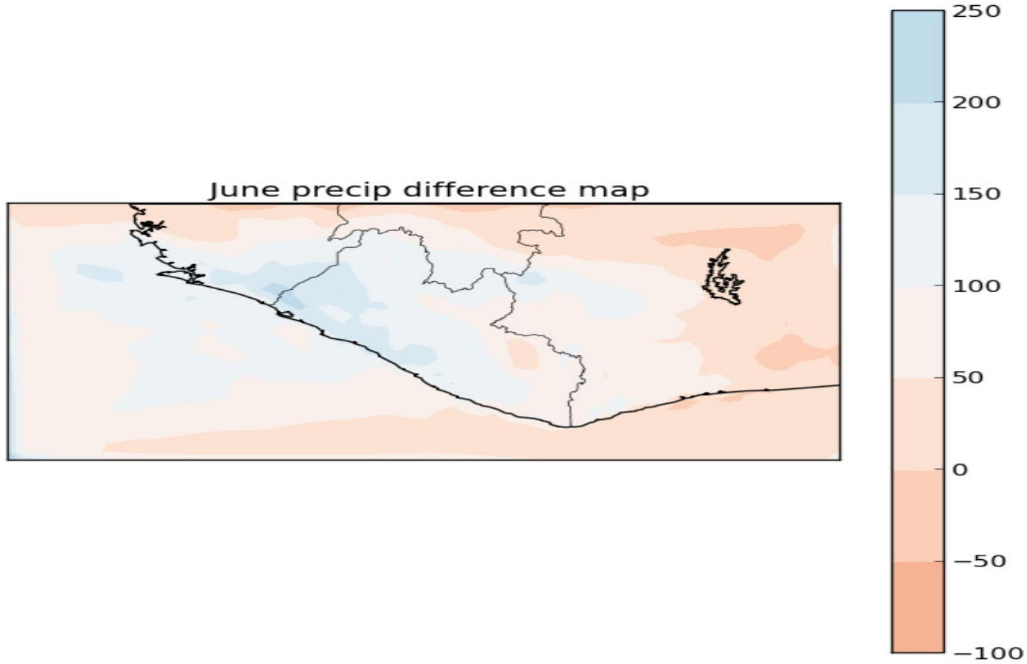


Figure 67: Dynamically downscaled change in precipitation for June (mm) (Source USAID 2013).

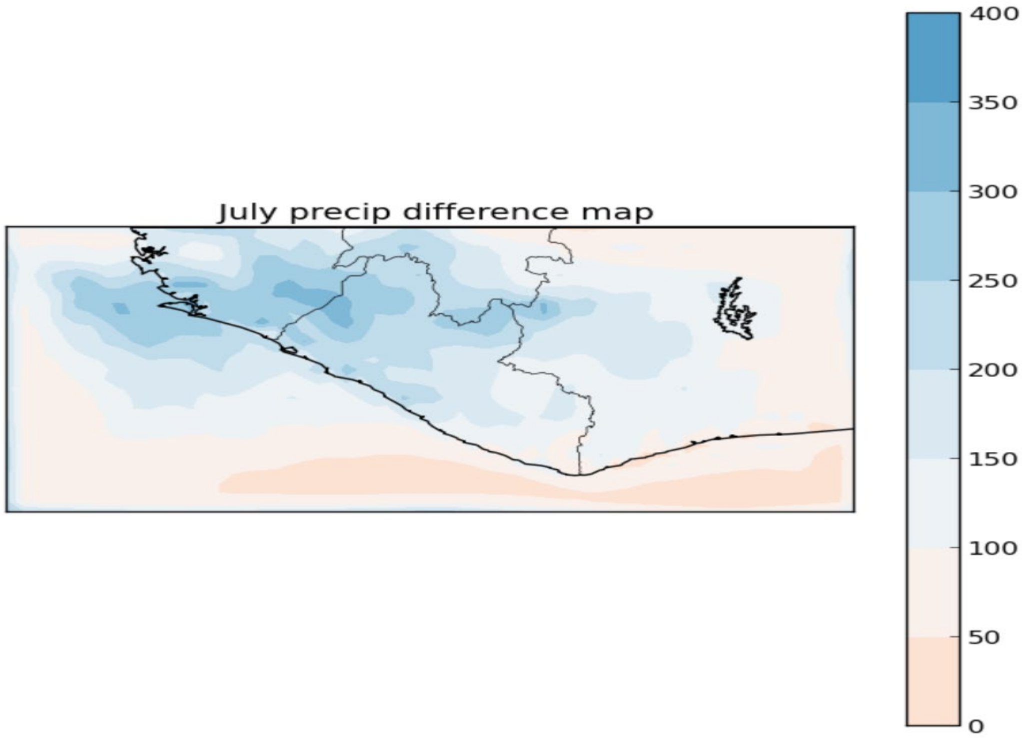


Figure 68: Dynamically downscaled change in precipitation for July (mm) (Source USAID 2013).

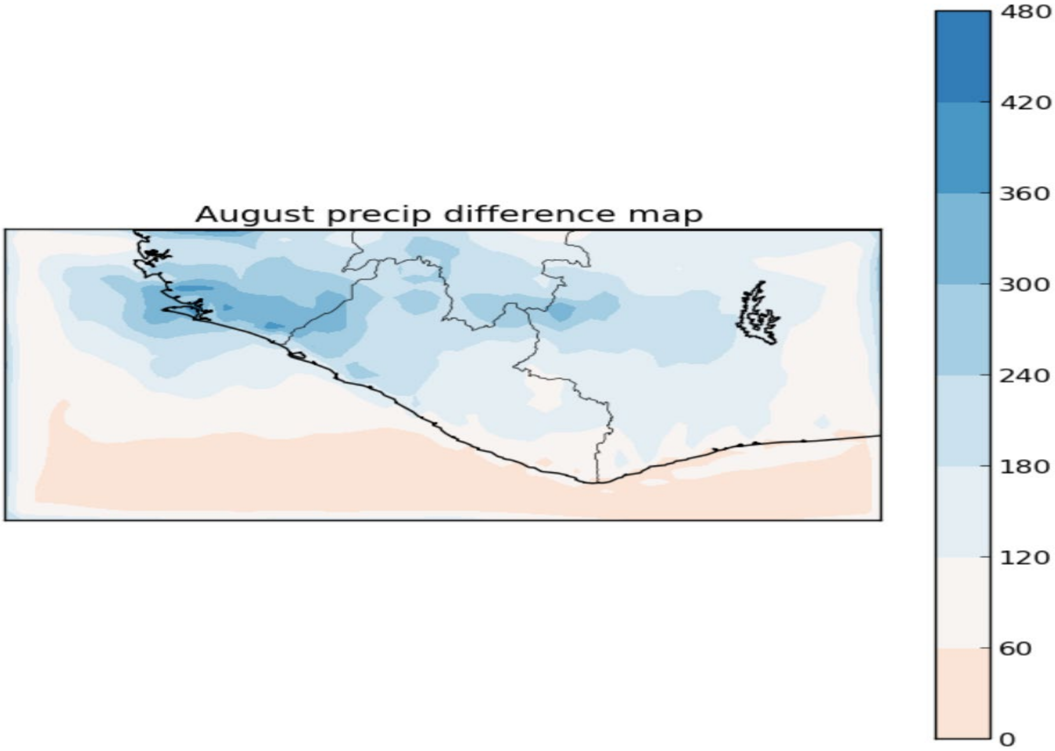


Figure 69: Dynamically downscaled change in precipitation for June (mm) (Source USAID 2013).

iv. Statistical Versus Dynamic Downscaling

The two common methods of downscaling climate information for global circulation models (GCMs) are statistical and dynamic downscaling. Statistical downscaling is based on establishing relationships between GCM data and observations for current conditions. These relationships are then used with GCM projections of future conditions to provide estimates of climate change at grid points closest to the observing stations. The primary limitations of statistical downscaling include the assumption that the statistical relationships between GCM and observations are time-invariant, and that the resolution of features is tied to the density of observing stations. Information between observing stations is interpolated.

Comparison of the precipitation estimates from the statistical downscaling (Figure 19 to Figure 22) with the dynamic downscaling (Figure 27 to Figure 30) illustrates one difference between statistical and dynamic downscaling. In the statistical case, the precipitation pattern shows pronounced north-south banding; however, the major drivers of precipitation for the region tend to parallel the coast in the case of the sea breeze or be oriented more east-west in the case of the monsoon. The east-west orientation of the enhanced future rainfall in the dynamic case indicates a potentially more vigorous monsoon circulation. The ability to attach physical meaning to future changes in climate is an advantage of the dynamic downscaling process.

Overall, the dynamic downscaling projects a warmer and wetter climate for Liberia., an aridity index was created as the ratio of precipitation to evapotranspiration, to examine the potential impact on the vegetation of these competing factors. Note that for the statistical downscaling this ratio was multiplied by 100 to yield an integer index, here the more traditional decimal form of the index aridity index is used. The dynamic downscaling produces smaller changes in the annual aridity than the statistical downscaling with the country becoming less arid overall as the increased precipitation during the rainy season offsets the increases in evapotranspiration caused by the increased temperature (Figure 31). Unlike the statistical downscaling, no areas of major drying (decreased average annual aridity index) were produced by the dynamic downscaling.

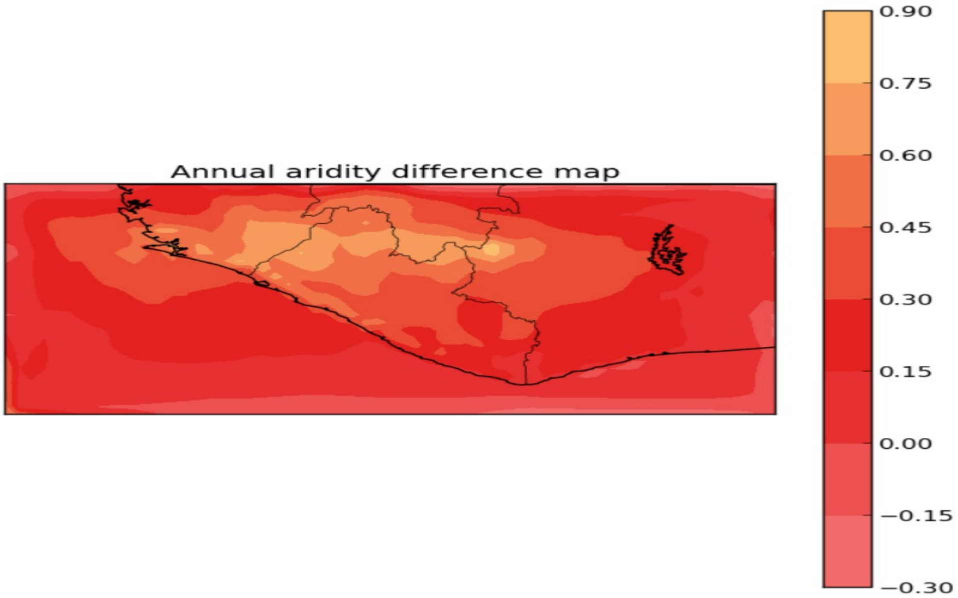


Figure 70: Change in average annual aridity from dynamic downscaling (Source USAID 2013).

4.2.3.2 Methodology 2: Climate Assessment using Representative Concentration Pathways

Another approach to assessing the state of the climate system is presented in this section. The purpose of this analysis is to provide an updated study based on a new assumption on the anthropogenic production of greenhouse gases, which could affect the Earth surface energy balance. The future project is done using the Coupled Model Intercomparison Project (CMIP) phase 5 (CMIP5; Roehrig et al. 2013) and Coordinated Regional Downscaling Experiment (CORDEX, Giorgi et al. 2009; Jones et al. 2011) framework. These projects constitute a set of coordinated and thus consistent and increasingly well-documented climate model experiments.

To gain insight on how these climate parameters are expected to change in the future regional climate model simulations from the CORDEX was employed. The CORDEX was established to provide global coordination of regional climate downscaling to investigate the historical and future climates of regions, and to provide useful climate information required for climate adaptation planning, impact assessment, and policymaking.

In this analysis, three-member model ensemble was computed from the Rossby Centre (SMHI) regional climate model (RCA4; Dieterich et al. 2013); the Consortium for Small-scale Modelling (COSMO) Regional Climate Model (COSMO-CLM; Panitz et al. 2014); and the MPI Climate Service Centre Germany (GERICS) Regional Model (REMO) v2009. These regional climate models are used to downscale the Climate Service Centre, Max Planck Institute for Meteorology Earth Systems Model low resolution (MPI-ESM-LR) in the CMIP5. The ensemble data is used in the analysis of the current study. The model ensemble was evaluated against observed rainfall and temperature from Global Precipitation Climatology Centre (GPCC) and European Centre for Medium-Range Weather Forecast Re-Analysis (ERA-Interim) data, respectively.

RCMs are limited-area models with representations of climate processes comparable to those in the atmospheric and land surface components of AOGCMs, though typically run without the interactive ocean and sea ice. RCMs are often used to dynamically 'downscale' global model simulations for some geographical region to provide more detailed information (Laprise, 2008; Rummukainen, 2010). By contrast, empirical and statistical downscaling methods constitute a range of techniques to provide similar regional or local detail. The analysis considers two representative concentration pathways (RCPs). The RCPs presents a consistent range of possible changes in future human-induced greenhouse gas (GHG) emissions and aim to represent their atmospheric concentrations with the possibility to create surface energy imbalance of 4.5 and 8.5 Wm^2 (Collins et al., 2013; RCP 4.5 and RCP 8.5 among others). The RCP 4.5 assumes emissions peak around 2040, while the RCP 8.5 assumes that emissions continue to rise throughout the 21st Century (Meinshausen et al., 2011).

a) Future Temperature Projection

Climate models predict that the annual average temperature in Liberia will rise in the future, as shown in **Figure 32**. The model ensemble predicts an average temperature rise of 1.5 - 4.5^{o}C during the 21st Century relative to the baseline period 1976-2005. The amount of predicted warming differs based on the model emission scenario, which assumes the number of emissions in the future. For the periods 2031-2060 and 2071-2100 warming of about 1.5 ^{o}C and 2.0 ^{o}C, respectively, is projected with RCP4.5. Historical trends in annual mean surface temperature derived from Climate Research Unit (CRU) observation and historical trends in annual mean surface temperature derived from a regional climate model (RCM) participating in the Coordinated Regional Climate Downscaling Experiment (CORDEX) framework, Climate Limited-area Modelling Community (CCLM v4.8.17; hereafter CCLM) are statistically significant at 95% confidence interval (Figure 33). If the level of greenhouse gases increases further as a result of continuous human activities, this will cause more warming, especially with the RCP8.5 scenario. The RCP8.5 runs projects warming of 2 ^{o}C in the period 2031-2060 and even more reaching 4.5 ^{o}C warming during the 21st Century than observed in the last epoch of the 20th Century. This potential climate change signal predicted can impact different regions in Liberia differently. For example, the increasing temperature can increase evaporation activities, which may enhance rainfall activities along the coastal region of the country.

b) Future Rainfall Projection

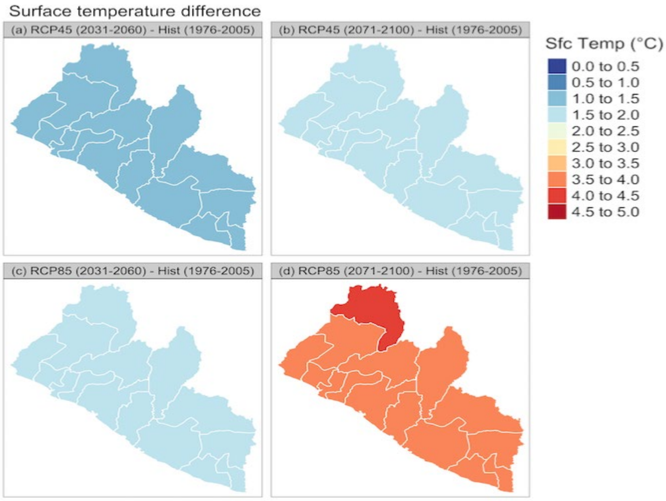


Figure 72: Predicted surface temperature differentials between a baseline period (1976-2005) and future periods (2031-2060 and 2071-2100) for RCP4.5 and RCP8.5

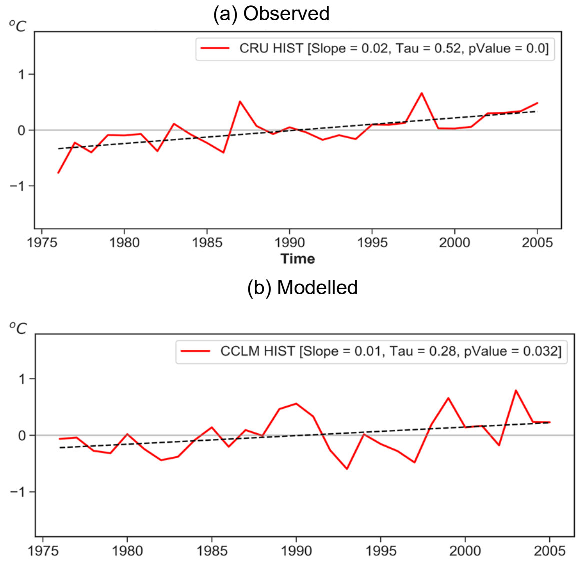


Figure 71: Trends in (a) observed and (b) modelled annual mean surface temperature over Liberia. The black dash lines indicate linear trends in the variable. The plotted values are anomalies relative to historical periods 1979-2005.

The model ensemble predicts similar rainfall distribution pattern relative to the baseline. It is, however, crucial to know how the rainfall is likely to vary in the context of warming and emission pathways. Figure 34 depicts the percentage change of projected rainfall relative to the baseline rainfall period 1976-2005 in Liberia. Similar to temperature, the projections are derived from the 3-member model ensemble within the CORDEX framework. Each projection is split into two climate regimes; near (2031-2060) and far (2071-2100) future and used to compute the percentage difference relative to the baseline (1976-2005) rainfall.

The model predicts an increase and decreases rainfall regimes within the range of -30 to 20% across Liberia. A common feature is a dryer condition towards the inland as indicated by negative percentage difference and wetness along the coast, most especially in the southernmost part of the country. For the RCP4.5, the rainfall differential lies between -10 to 15%. During the 2071-2100 periods (see Figure 34b&d), the rainfall increase becomes more widely spread around the southern end of the country. Both observed and modelled historical trends in rainfall show increasing trends (Figure 35). The trend is statistically significant in CRU. Under a worst-case scenario (RCP8.5) the model predicts increased rainfall of about 5% and above across the vast coastal counties of the country. Also, the model predicts a more intense drying condition over the eastern lateral half of the country (Figures 34c and d). This phenomenon intensifies (i.e. reaching -30%) in the last climate epoch of the 21st Century (2071-2100).

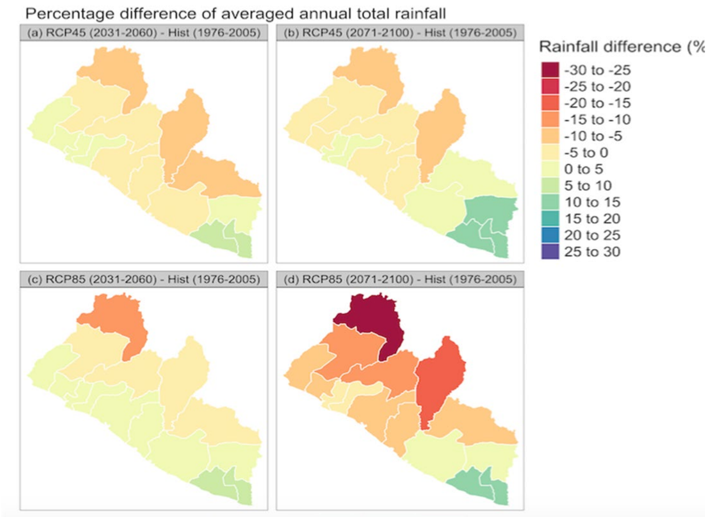


Figure 73: Percentage changes of projected rainfall relative to the baseline period 1976-2005 over Liberia for future periods (2031-2060 and 2071-2100) under RCP4.5 and RCP8.5

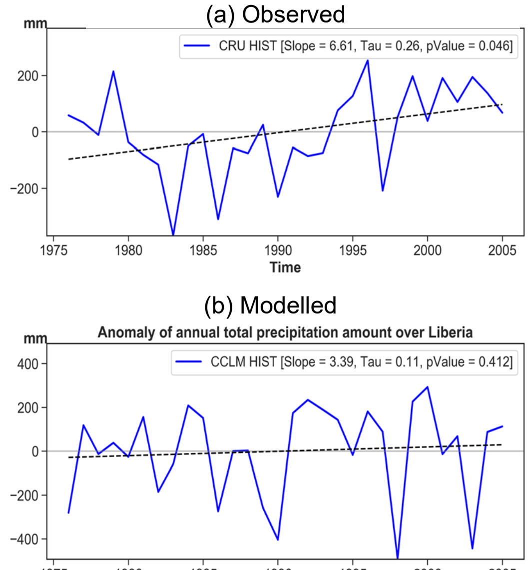


Figure 35: Trends in (a) observed and (b) modelled rainfall over Liberia. The black dash lines indicate linear trends in the variable. The plotted values are anomalies relative to historical period 1979-2005.

The projections are derived from the 3-member model ensemble within the CORDEX framework. Two radiative forcing scenarios, representative concentration pathways (RCP45 and RCP85), were used. Each projection was split into two climate regimes: near (2031-2060) and far (2071-2100) future.

4.2.4 Projected Core Sector-Specific Climate Indices

Climate indices are useful indicators that allow us to understand and explain the state and changes in the climate system. This importance led to the establishment of the World Meteorological Organization (WMO) Commission for Climatology (CCl) Expert Team on Sector-specific Climate Indices (ET-SCI). The terms of reference for the established ET-SCI seeks to support the eventual implementation of the Global Framework for Climate Services (GFCS; see http://www.wmo.int/hlt-gfcs/downloads/HLT_book_full.pdf). The ET-SCI functions within CCl under the Open Panel of CCl Experts (OPACE) on Climate Information for Adaptation and Risk Management (OPACE-4). The objective of OPACE-4 is to improve decision-making for planning, operations, risk management and for adaptation to both climate change and variability (covering time scales from seasonal to centennial). It will be achieved through a higher level of climate knowledge, as well as by access to and use of actionable information and products, tailored to meet their needs (https://epic.awi.de/id/eprint/49274/1/ClimPACTv2_manual.pdf).

Daily climate data (e.g. daily temperature and precipitation) unlike monthly averages of climate data, which smoothen out important information, helps to reveal valuable information that is relevant for sectorial impacts. The information derived is critical to answers questions concerning aspects of the climate system that affect many human and natural systems with emphasis on extremes. Such indices might reflect the duration or amplitude of heatwaves, extreme rainfall intensity and frequency or measures of extremely wet or dry/hot or cold periods that have socio-economic impacts.

Trend analysis of some WMO ET-SCI indices derived from observed and modelled climate records of daily maximum and minimum temperature and daily rainfall[11] was performed. The standardized software ClimPACT generates these sector-specific climate indices to define simple and complex climate risks and support its integration into the Climate Services Toolkit. Figure 36 presents projected trends in selected indices defined by the WMO ET-SCI. These include (a,b) cool nights (TN10P), (c,d) warm nights (TN90P), (e,f) warm days (TX90P), (g,h) warm spell duration index (WSDI), (i,j) very wet days (R95PTOT) and (k,l) extreme wet days (R99PTOT) plotted for the period 2041-2070 over Monrovia for corresponding future projections from the CLM model under RCP 4.5 and RCP 8.5 scenarios. The black lines indicate linear trends in the variable. The plotted values are anomalies relative to historical baseline period 1979-2005. Mann Kendall trend test was performed to examine the significance at 95% confidence interval.

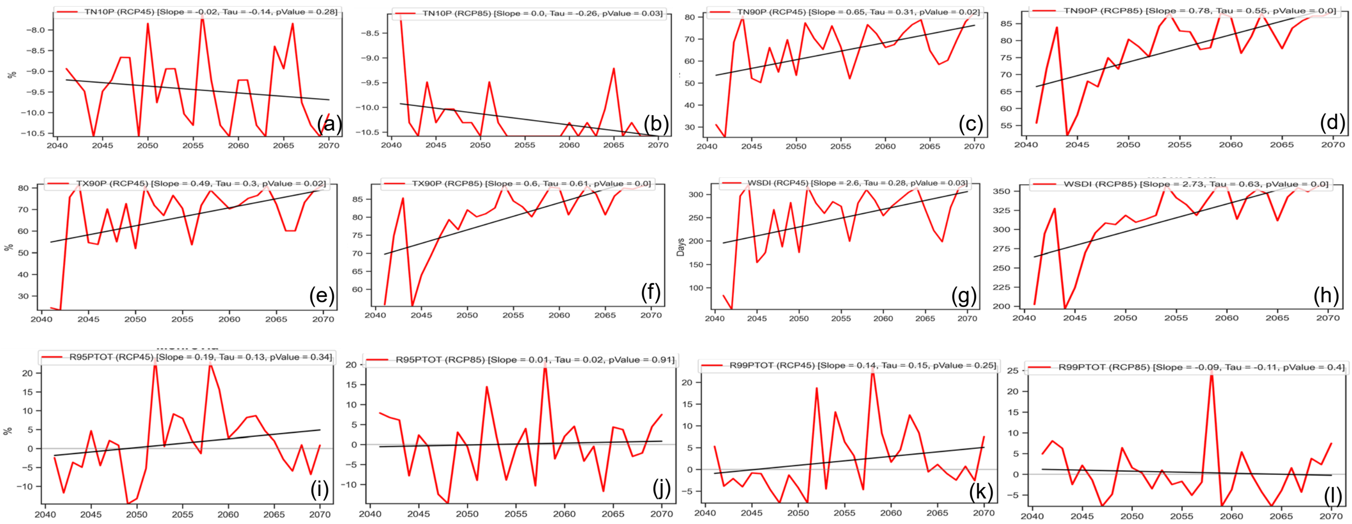


Figure 36: Projected trends in (a,b) cool nights (TN10P), (c,d) warm nights (TN90P), (e,f) warm days (TX90P), (g,h) warm spell duration index (WSDI), (i,j) very wet days (R95PTOT) and (k,l) extreme wet days (R99PTOT) over Monrovia. The indices are generated from daily minimum and maximum temperature using the WMO ET-SCI definitions for corresponding RCP4.5 and RCP8.5. The black lines indicate linear trends in the variable. The plotted values are anomalies relative to historical period 1979-2005. Mann Kendall trend test was performed to examine the significance at 95% confidence interval.

Projected percentage of TN10P is expected to decrease by 10% compared to the baseline period while trends in index is likely to decrease under RCP4.5 and RCP8.5 scenarios. The modelled decreasing trend is significant under RCP8.5. TN90P show a general increase relative to the baseline (about 80% increase) in the two scenarios. The increasing trend in this index is statistically significant at 95% confidence interval. For TX90P, the model projects a positive change of about 80% and 90% under RCP4.5 and 8.5, respectively. Also, the projected trends are increasing significantly in both scenarios. Trends in WSDI are likely to significantly increase as produced in the model. The difference between the projected and baseline period show possible increase of WSDI, which lies within the range of 100-300days or more in the future. The warming trends found in the model are consistent with recent research where CORDEX simulations over the Pan-African domain show consistency with their driving global model and revealed a

[11] https://climpact-sci.org/indices/

robust regional warming exceeding the mean global one over most regions in Africa[12]. In the same study, the highest increase in annual mean temperature is found over the subtropics and the lowest over many coastal regions. Also reported is that projected changes in annual mean precipitation have a tendency to produce wetter conditions in some parts of Africa including central/eastern Sahel and eastern Africa at both 2 °C and 1.5 °C global warming levels (GWLs), although models' agree less in terms of the sign of change. In addition, a consistent difference between 2 °C and 1.5 °C warmings was found for projected changes in annual mean temperature and daily precipitation intensity, which could pose dare implications on African climate and its extremes. Although, not significant, contributions from very wet days (R95PTOT) and extreme wet days (R99PTOT) in the current assessment is expected to increase up to 25% in both scenarios. However, the magnitude of this increase is found to be lesser in RCP8.5. A comprehensive statistical summary of the Mann Kendall trend analysis is presented in Table 12.

Table 12: Statistical summary of Mann Kendall trend test. Bold values are statistically significant trends at 95% confidence interval

Indices	Slope		Tau		p-value	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
TN10P	-0.02	0.00	-0.14	-0.26	0.28	**0.03**
TN90P	0.65	0.78	0.31	0.55	**0.02**	**0.00**
TX90P	0.49	0.60	0.30	0.28	**0.02**	**0.00**
WSDI	2.60	2.73	0.28	0.63	**0.03**	**0.00**
R95PTOT	0.19	0.01	0.13	0.02	0.34	0.91
R99PTOT	0.14	-0.09	0.15	-0.11	0.25	0.40

[12] Nikulin, G., Lennard, C., Dosio, A., Kjellström, E., Chen, Y., Hänsler, A., Kupiainen, M., Laprise, R., Mariotti, L., Maule, C.F. and van Meijgaard, E., 2018. The effects of 1.5 and 2 degrees of global warming on Africa in the CORDEX ensemble. Environmental Research Letters, 13(6), p.065003.

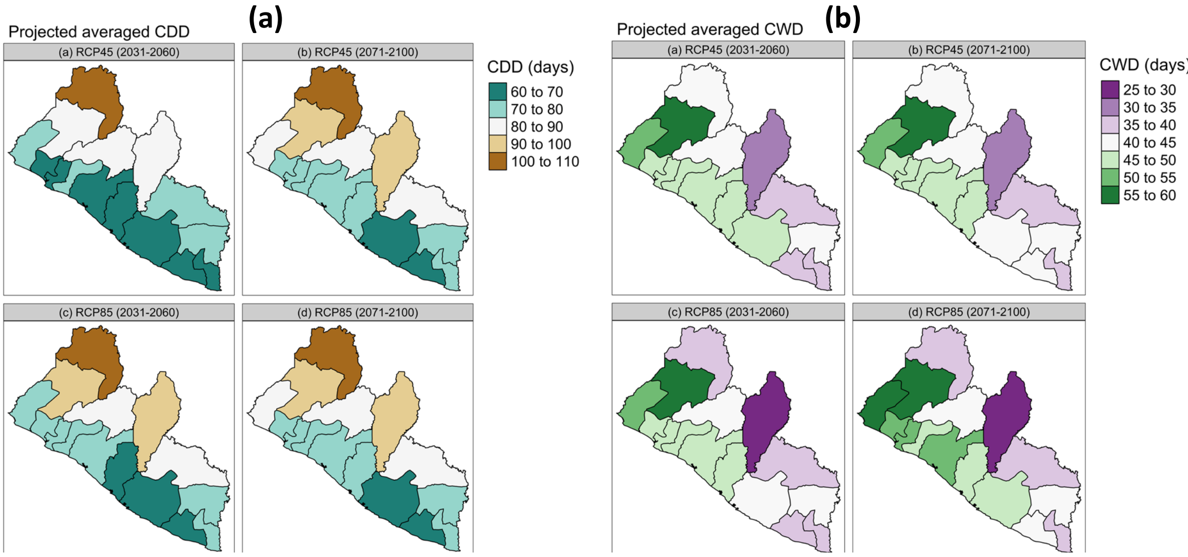


Figure 37:Maximum number of consecutive days with daily rainfall (a) less than 1 mm (CDD) and (b) greater than or equal to 1 mm (CWD) for RCP4.5 and RCP8.5 averaged over 2031-2060 and 2071-2100.

Spatial distribution analysis of some other WMO ET-SCI indices relevant to specific-sectors, especially agriculture, health, and water sectors is presented in this Section. Figure 37a depicts the model consecutive dry days (CDD) of two 30-year climate regimes (2031-2060 and 2071-2100) for the RCP4.5 and RCP8.5. This index describes the maximum number of consecutive days with daily rainfall less than 1 mm. Model projects CDD will increase (decrease) around inland (coastal) areas. Increase in CDD could be unhealthy for plant growth and development in inland areas where the change is pronounced

For a maximum number of consecutive days with rainfall greater than or equal to 1 mm (CWD), the model project more days along most coastal areas to the north of the country (Figure 37b). Inland areas are expected to experience fewer wet days, most especially in Nimba County, where CWD is less than 30 days. These potential changes in CWD could lead to different diverse health issues in Liberia.

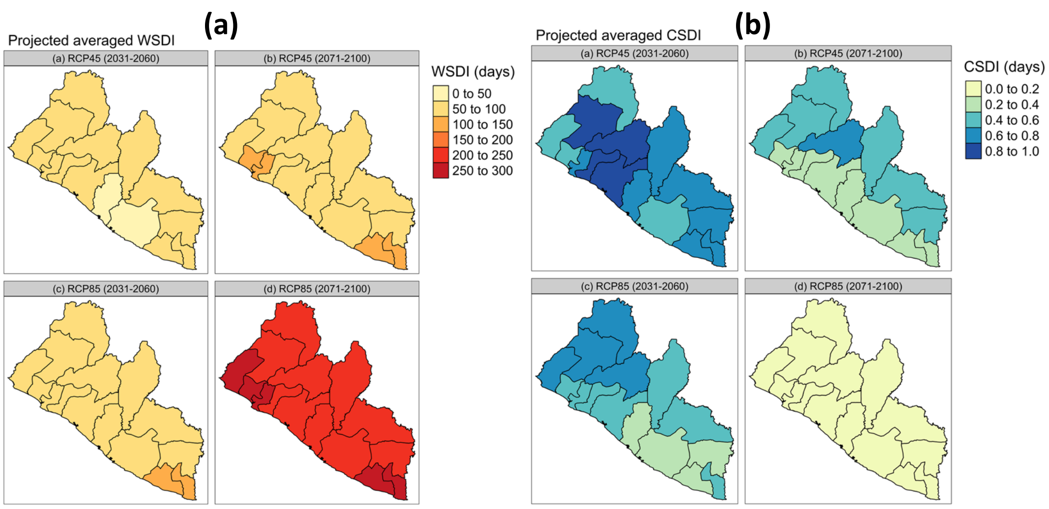


Figure 38: Modeled averaged (a) warm spell duration indicator (WSDI) and (b) cold spell duration indicator (CSDI) for RCP4.5 and RCP8.5 averaged over 2031-2060 and 2071-2100.

Indicator of a warm spell, WSDI - annual count of at least six consecutive days when the maximum temperature is greater than 90th percentile, is projected to reach almost 300 days in 2071-2100 of RCP8.5. Still, less than 100 days is anticipated in most regions during 2031-2060 of the same scenarios (Figure 38a). For RCP 4.5, the warm spell days are on the average less than 150 per annum. On the contrary, CSDI events, an annual count of at least six consecutive days when minimum temperature is less than 10th percentile, are very few (Figure 38b).

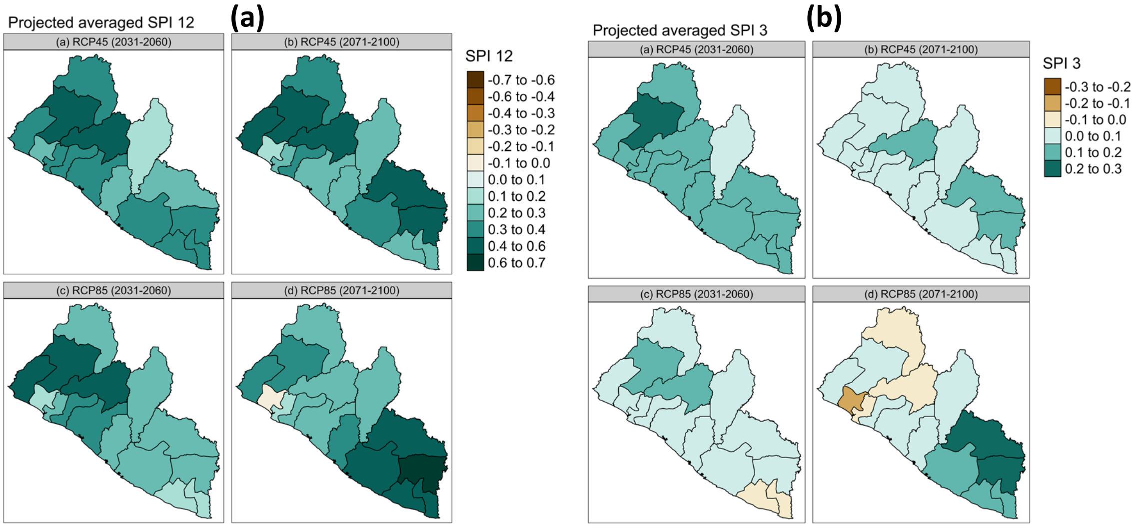


Figure 39: Average standardized precipitation index (SPI) for (a) 12 months and (b) 3 months for RCP4.5 and RCP8.5 averaged over 2031-2060 and 2071-2100.

The Standardized Precipitation Index (SPI) is a measure of drought that can be done on different time scales. Figure 39 depicts SPI of 3 and 12 months. Figure 39a shows that the chance of experiencing 12 months drought, which is a reflection of annual drought, in the future is mild in Liberia. This implies minimum stress on activities related to hydropower generation. In Figure 39b, the three months (seasonal) drought is expected to occur, but such drought is mild in the northern parts of the country. Seasonal drought is expected to impact the growing of seasonal crops. Thus, the need to promote the use of drought-tolerant varieties for seasonal crops in addition to adopting climate-smart agricultural practices for precision farming to ensure food security.

4.2.5 Climate Change Impacts, Risks and Vulnerabilities

Liberia has been experiencing series of climate hazards that caused catastrophic damage to socioeconomic activities in the country. For example, in August 2007, Liberia experienced a severe flooding that disrupted livelihoods, displaced hundreds of people, severely damaged homes, and cut off piped water to 250,000 people in Monrovia (IRIN, 27/08/2007) and caused serious shortage of safe drinking water, as water points become polluted. In September 2007, 17,000 people were directly affected by floods (OCHA, 25/09/2015). These predicaments will only get worse under the projected rise in temperature in the future. A severe flooding in 2018 covered most counties in Liberia including Margibi, Montserrado, Grand Bassa, Bomi, Sinoe Grand Kru and Maryland Counties, directly affecting about 52,726 people. Among those affected people, 44% were females, while 18% were children and the remaining 38% are males. The NDMA stated that majority of those affected were females and nearly a quarter of the affected individuals were children. Similarly, occasional heavy precipitation events were experienced during the summer monsoon of 2019. This event, which was widely felt across most coastal regions in Liberia, directly affected more than 60,000 people according to the first preliminary NDMA report for 2019. Most of these individual rainfall events were received during the peak of the 2019 monsoon season (July) across Liberia. Flooding has resulted in the cut off of the Roberts International Airport Highway and access to the airport, major international hub into and out if the country. A similar event also occurred in 2016. Furthermore, the inundation disrupted livelihood; caused a shortage of safe drinking water, as water points were polluted, which has made affected residents drink contaminated water. Flooding raised high risk of disease outbreaks (cholera, diarrhoea, malaria, etc.), food insecurity, drowning, and injuries, damage of dwellings and even deaths.

The climate scenarios discussed in Section 4.2.4 present dire economic and social implications for the country. Liberia lost approximately 0.02 per unit gross domestic product (GDP) from 1994 to 2013 from climate hazard[13]. This resulted in an estimated annual loss amounting to US$3.79 million in 2013 and US$ 7.44 million in 2017. The cumulative potential losses resulting from climate hazards in Liberia under the baseline scenario will increase from US$ 55 million in 2021 to US$ 136 million in 2030, a net increase of US$ 86 million in the next decade. The baseline results from a model simulating the impact of climate change in Liberia, anchored on GDP, indicated that a minimum of 7,000 Liberians annually suffers direct impacts from climate-related hazards and disasters. This number, under the baseline scenario, is expected to almost triple to 15,416 people. Given that GDP, as a proxy does not fully capture the climate impact, the actual minimum impact of climate-related disasters such as flooding and coastal erosion is estimated to be over 100,000 people presently. In extreme climate scenarios resulting in droughts, floods, coastal erosion, among others, the people affected annually in the next two decades could increase to 177,289 people.

The government of Liberia is severely handicapped when it comes to equipping its institutions to mitigate and adapt to climate change. The NDMA received only 19% (US$930,000) of its proposed budget (USD$3,939,695) to the government in 2018. The amount the Agency received was far less than the minimum (USD$1,904,444) it requires to operate.

In 2007, Liberia experienced severe flooding that disrupted livelihoods, displaced hundreds of people, destroyed or severely damaged homes, and cut off piped water to 250,000 people in Monrovia (IRIN, 27/08/2007) and caused a serious shortage of safe drinking water, as water points become polluted. In September 2007, 17,000 people were directly affected by floods (OCHA, 25/09/2015). These predicaments will only get worse under the projected rise in temperature in the future.

Severe flooding in 2018 covered most counties in Liberia including Margibi, Montserrado, Grand Bassa, Bomi, Sinoe Grand Kru and Maryland Counties, directly affecting about

[13] https://germanwatch.org/sites/germanwatch.org/files/publication/10333.pdf

52,726 people. Among these affected people, 44% were females, while 18% were children and the remaining 38% are males. The NDMA stated that the majority of those affected were females, and nearly a quarter of the affected individuals were children.

Similarly, occasional heavy precipitation events were experienced during the summer monsoon of 2019. The events, which was widely felt across most coastal regions in Liberia, directly affected more than 60,000 people according to the first preliminary NDMA report for 2019. The government funding to disaster activities is low, while disaster risk to the population is ever increasing. Most of these individual rainfall events were received during the peak of the 2019 monsoon season (July) across Liberia. Flooding has resulted to the cut off of the Roberts International Airport Highway and access to the airport, major international hub into and out if the country. A similar event also occurred in 2016.

Furthermore, the inundation disrupted livelihood; caused a serious shortage of safe drinking water, as water points were polluted, which has made affected residents drink contaminated water. Flooding raised high risk of disease outbreaks (cholera, diarrhoea, malaria, etc.), food insecurity, drowning, and injuries, damage of dwellings and even deaths.

Liberia experiences continuous climate risks and hazards along its coastal belt. There is unfavourable geomorphology along the coastal zone, exposing it to unobstructed forces of Atlantic Ocean swell waves. The potential temperature rises of up to 4.5 degree Celsius will further accelerate the recurring disasters, including flooding and erosion that has already swept a large number of houses through the years and along coastal counties.

Floods destroyed crops and farmlands, compelling the Government of Liberia (GOL), in partnership with other organisations, to make a series of interventions to provide food and non-food items to affected communities. Many households have already exhausted their coping strategies and are increasingly vulnerable. The food insecurity crisis is projected to increase to 720,000 people (15% of the population) in the lean season (June–August). A projected temperature rise in the future will compound the food insecurity problem and, therefore, demands immediate adaptation measures to counteract the impacts.

Furthermore, extreme weather such as storm can disrupt airline travels and present extraneous economic circumstances. In Liberia, flooding has caused cut-offs at the Roberts International Airport Highway and access to the airport, a major international hub into and out of the country (Figure 40). Most recently, in 2016, a similar experience was reported.

Figure 74: People cross the flooded road to Monrovia airport on after heavy rains. - Heavy rains have cut the only road access to Liberia's main airport, leaving travellers to cross some sections by canoe. At certain points the only road between the capital Monrovia

The temperature forecasts present a dire climatic and economic outlook for Liberia. The country is increasingly vulnerable to climate risks and climate-related hazards because of its low adaptability, a result of weak human and institutional capacities, technology, infrastructure, financial systems, amongst others. Climate vulnerability severely impacts Liberia's priority sectors, including agriculture, food security, health, energy, water resources, forestry and wildlife, fishery, mining, industry, transport, and tourism[14].

The scale below indicates the threat to food security in Liberia.

Likely to occur within the next six months	Probability	Very low	Low X	Moderate	Significant	High
Estimated humanitarian impact	Impact	Insignificant	Minor	Moderate	Significant X	Major
Up to 850,000 people affected						

The disruption to the agricultural system resulting from climate-induced changes in patterns of rainfall and temperature has disastrous implications for a country where more than 70% of the population is engaged in agriculture as their primary source of livelihood. Similarly, sea-level rise induced flooding in Liberia is another immediate threat to economic growth by affecting energy supply and damaging transport infrastructure. Moreover, the adverse effect of climate change has been exerting pressure on inland, coastal, and marine aquatic resources15 as well as on energy accessibility and efficiency, industrial activity, settlements, and urbanisation. Climate change-induced extreme events are also limiting the ability of forest dwellers to meet their basic requirements for food due to a reduction in the amount of productive land and pest infestation of crops.

[14]National Policy and Response Strategy on Climate Change (2018)

[15] Giorgio V. B. and Mohammed T. (2006) Liberian Environmental Profile Preliminary Report. December 2006

An increase in temperature in the future will present challenging climatic outcomes with dire consequences on health. Liberia is prone to flooding, and the rising temperature can worsen the situation. Flooding raised high risk of outbreaks of diseases such as cholera, diarrhoea, malaria, food insecurity, drowning, and injuries, damage of dwellings and even deaths. The threat of infectious diseases is depicted in the scale below.

Likely to occur within the next six months	Probability	Very low	Low	Moderate X	Significant	High
Estimated humanitarian impact	Impact	Insignificant	Minor	Moderate X	Significant	Major
Up to 50,000 people affected						

Climate change presents a range of health implications on the global economy, especially in developing countries such as Liberia. The COVID-19 pandemic, for example, impacts the ability of agencies to generate climate data to combat climate change. Climate change undermines environmental determinants (biological, chemical, physical, social, or cultural) of health. The epidemic places additional stress on health and food systems, and the impact of climate such as flooding undermines strict adherence to the social distancing measures as an intervention mechanism to curb the spread. The World Meteorological Organization (WMO) has further warned that “the coronavirus pandemic risks disrupting key forecasting services, including early warning alerts around the world”. The projected increased temperature (1.5 to 4.5 degree Celsius) will, therefore, escalate the stress on the existing health infrastructure to respond to diseases and other biological crises.

Most emerging infectious diseases, and almost all recent pandemics, originate in wildlife, and there is an indication that increasing human pressure on the natural environment may steer disease emergence. This disease has a high potential of threatening lives, crippling businesses, and damaging the already fragile economy in Liberia, as well as threatening the achievement of the SDGs in the country. Therefore, there is an urgent need to strengthen resilience and mitigate climate change by promoting legislation to cut greenhouse gas emissions to limit global temperature rise to 1.5 degrees above pre-industrial levels.

However, measures to recover from the coronavirus brings a profound opportunity to drive national planning process through a path that tackles climate change, protect the environment, reverse biodiversity loss and ensure long-term health and security of lives and livelihoods of the most vulnerable people of Liberia. Liberia can only trail this path and take necessary climate action to align with the common global framework, such as the 2030 agenda for SDGs, the Paris Agreement and Sendai framework on DRR. Adequate finance from the GCF and other donor partners and appropriate climate-smart technology is therefore crucial to support this process.

For instance, the outbreak of COVID-19 pandemic has resulted in a drastic decline in data of opportunity such as aircraft observations because of the overall reduction in global flight operations (i.e. about 80% since February). Surface observations have also reduced drastically, especial in Africa, where there is over-reliance on manned observing stations which were unavoidably truncated due to the lockdown restrictions. Ocean observations were not exempted from the impact of this pandemic as 80% reduction voluntary ship observation relative to the pre-COVID-19 baseline was reported. These pieces of evidence justify the need to fully automate observing systems for improved reporting frequency and resilience and highlight the importance of the WMO Global Basic

Observing Network (GBON) Systematic Observations Financing Facility (SOFF)[16].The GBON SOFF is a finance mechanism created through the Alliance for Hydromet Development to provide equitable, predictable, and sustainable finance for a foundational global public good. Liberia will, however, leverage on this instrument to strengthen and modernize their observing network to be less vulnerable and more resilient to different types of crisis, including those similar to COVID-19.

Most emerging infectious diseases, and almost all recent pandemics, originate in wildlife, and there is an indication that increasing human pressure on the natural environment may steer disease emergence. This disease has a high potential of threatening lives, crippling businesses, and damaging the already fragile economy in Liberia, as well as threatening the achievement of the SDGs in the country. Therefore, there is an urgent need to strengthen resilience and mitigate climate change by promoting legislation to cut greenhouse gas emissions to limit global temperature rise to 1.5 degrees above pre-industrial levels. The projected increased temperature (1.5 to 4.5 degree Celsius) will, therefore, escalate the stress on the existing health infrastructure to respond to diseases and other biological crises.

It is, therefore, imperative to upscale existing hydrometeorological systems to provide timely, accurate, and actionable climate information for Liberia to effectively respond and adapt to climate risks. The proposed project builds on previous projects to help Liberia build a streamlined, customised, and consolidated EWS informed by robust science, technology, and decision-making.

The government funding to disaster activities is low, while disaster risk to the population is ever increasing. This is because the government of Liberia is severely handicapped when it comes to equipping its institutions to mitigate and adapt to climate change. For instances, the NDMA received only 19% (US$930,000) of its proposed budget (USD$3,939,695) to the government in 2018, which is far less than the minimum (USD$1,904,444) it requires to operate.

Despite this funding gap, Liberia continues to experience increasing climate risks and hazards along its coastal belt. There is unfavourable geomorphology along the coastal zone, exposing it to unobstructed forces of Atlantic Ocean swell waves. The potential temperature rises of up to 4.5 degree Celsius will further accelerate the recurring disasters, including flooding and erosion that has already swept a large number of houses through the years and along with coastal counties.

Though the likelihood of having such a problem occurring at the interval of 6 months is low, the estimated humanitarian impact is quite significant and could affect up to 850,000 people[17.] The disruption to the agricultural system resulting from climate-induced changes in patterns of rainfall and temperature has disastrous implications for a country where more than 70% of the population is engaged in agriculture as their main source of livelihood. Similarly, sea-level rise induced flooding in Liberia is another immediate threat to economic growth by affecting energy supply and damaging transport infrastructure. Moreover, the adverse effect of climate change has been exerting pressure on inland,

[16] https://public.wmo.int/en/innovating-finance-%E2%80%93-systematic-observations-financing-facility-0

[17] https://reliefweb.int/sites/reliefweb.int/files/resources/r-acaps-liberia-risks-28-may-2015.pdf

coastal, and marine aquatic resources[18] as well as on energy accessibility and efficiency, industrial activity, settlements, and urbanization. Climate change-induced extreme events are also limiting the ability of forest dwellers to meet their basic requirements for food due to a reduction in the amount of productive land and pest infestation of crops.

An increase in temperature in the future will present challenging climatic outcomes with dire consequences on health. Liberia is prone to flooding, and the rising temperature can worsen the situation. Flooding raised high risk of outbreaks of diseases such as cholera, diarrhoea, malaria, food insecurity, drowning, and injuries, damage of dwellings and even deaths. The threat of communicable diseases is expected to moderately increase with estimated moderate humanitarian impact on about 50,000 at an interval of 6 months19.

Reports from the fifth assessment of the Intergovernmental Panel on Climate Change[20] stated that continued emission of greenhouse gases cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. For instance, projected regional warming in West Africa is estimated at 1–1.5 °C by 2099, threatening the stability of current ecosystems[21]. To limit human-induced climate change will require substantial and sustained reductions in greenhouse gas emissions (i.e. mitigation), which, together with adaptation, can limit climate change risks[22].

The concept of vulnerability to climate change is increasingly dominating discussions in Liberia political space with the aimed to help society to adapt to and or mitigate the impact of climate change. Vulnerability to climate change impact can be defined as a function of exposure, sensitivity and adaptive capacity. Actions to address climate change in Liberia seeks to adopt an effective approach that would be informed by sectoral needs within the national/local circumstances[17], which are constantly changing. The estimated cost of interventions needed in the priority sectors amounts to USD $1.94 billion[17].

Some of the key sectors adversely affected by climate change include forestry and wildlife, agriculture and food security, coastal areas, water, fisheries, energy, mining, industry, transport, tourism, infrastructure, urbanization and settlement, and health. The brief overview of climate risk associated with key sectors in Liberia is described in Figure 41.

[18] Giorgio V. B. and Mohammed T. (2006) Liberian Environmental Profile Preliminary Report. December 2006

[19] https://reliefweb.int/sites/reliefweb.int/files/resources/r-acaps-liberia-risks-28-may-2015.pdf

[20] IPCC (2014). Summary for policymakers. In Climate Change 2014: Impacts, Adaptation, and Vulnerability.

[21] Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M., 2013. Climate change 2013: The physical science basis.

[22] National Policy and Response Strategy on Climate Change (2018)

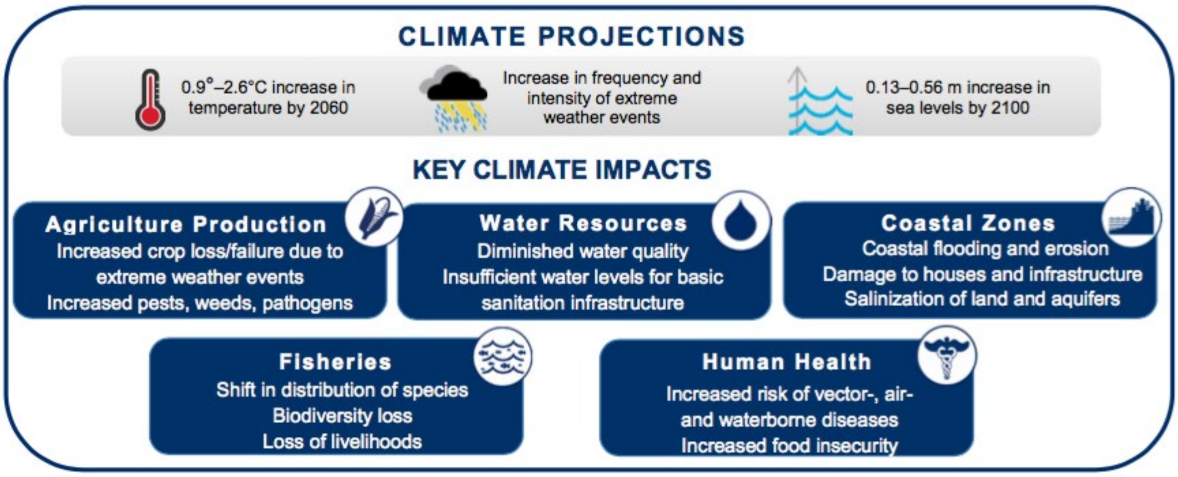


Figure 75: Overview of climate risk in priority sectors*(Source: USAID, 2017)*[23]

i. **Forestry and Wildlife**

Forests cover about 4.30 million hectares or 45 percent of the land area in Liberia. However, in recent years the area coverage has significantly decreased, consequent to uncontrolled logging and an expansion of land used for agriculture. The average annual rate of deforestation since 2001 and over a reference period of 2005 to 2014 is 0.46% (FDA, 2016). Also, the recorded planting of new forests to date has amounted to only about 11,000 hectares. Though Liberia is small in size, it contains a significant amount of biodiversity (flora and fauna), including over 2,900 different vascular plants (including 225 tree species); 600 bird species, 150 mammal species, and 75 reptile species.

In addition to shifting cultivation, changing climate plays an important role in forest health. It may worsen many of the threats to forests, such as pest outbreaks, fires, human development, and drought. Evidence also suggests that climate-induced changes on the ability of the forest ecosystem to provide basic goods and services will impact the economic and social well-being of forest-dependent communities negatively. The changing climate will undoubtedly contribute to the forest loss which will, in turn, lead to loss of wildlife, particularly associated with subsistence agriculture and the expansion of commercial agriculture to meet national food requirements for market, particularly with the tendency of increasing the price of rice and palm oil in the domestic and world market (FDA, 2006).

ii. Agriculture and Food Security

Liberia's agriculture sector is forest-based, dominated by traditional subsistence farming systems, mainly in the uplands, and characterized by labour intensity, shifting cultivation, low technologies, and productivity. Although rice, cassava and vegetable production accounts for about 87% of cultivated land, the output of the staple foods remains below national requirements. Agriculture-related imported products, of which food and live animals account for over a third, amounted to well over half (50%) of total imports in the post-war period, second only to petroleum products (MoA, 2015).

The production system of agriculture in Liberia is nature-dependent as the production activity that transforms inputs into agricultural outputs involves the direct use of weather

[23] USAID (2017) Climate Risk Profile in Liberia. The Climate Change Adaptation, Thought Leadership and Assessments (ATLAS).

inputs (precipitation, temperature, and solar radiation available to the plant), with various studies of the impacts of climate change on agriculture reporting substantial differences in outcomes such as prices and production. As climate predictions indicated in the above climate analysis Section, the increasing tendency of temperature and the high variability, but the increasing tendency for rainfall pattern, show that climate change continues to exert significant pressure on the agriculture sector. Similarly, the livestock sector, which contributes 14% of food and agricultural GDP (MoA, 2006), the pressure is expected as climate change hazards, as well as animal diseases and vectors, could affect the productivity of the sub-sector.

iii. Coastal Area

Liberia has an extensive coastline along the western boundaries. Settlements in coastal lowlands of Liberia are especially vulnerable to risks resulting from climate change. However, these lowlands are densely populated with settlements and growing rapidly (McGranahan et al., 2007). For example, it is projected that about 95 km^2 of land in the coastal zone of Liberia will be inundated as a result of one-meter sea-level rise, with about 50% (48 km^2) of the total land loss due to inundation being the sheltered coast. The Inundation will be followed by shoreline retreat (Wiles, 2005); yet the population of Monrovia continues to grow. The potential rise in sea levels could add to existing trends of coastal erosion in areas like Buchanan and Monrovia, with a loss in infrastructure and land of around $250 million apart from the social and psychological stress on the population (Tumbey, 2015; Wiles, 2005).

iv. Water Resources

The bulk of the major hydrologic features of Liberia are constituted by several large lakes and six main rivers (Mano, St. Paul, Lofa, St. John, Cestos and Cavalla), which drain the country with the north-south pattern. They drain 66% of the country. The short coastal watercourses drain about 3% of the country and include but not limited to the Po, Du, Timbo, Farmington, and Sinoe rivers. All of the six major rivers have considerable potential for hydroelectric power (the Republic of Liberia, 2004). Prior to the civil war, there were three operational hydroelectric power plants in Liberia: Harbel (Firestone), 4MW; Mount Coffee (LEC), 64MW; and Yandahun (a community micro-hydro in Lofa County), 30KW. The Mount Coffee and Yandahun plants were destroyed during the war but have both been made operational recently. A number of feasibility studies carried out over the period 1976-1983 identified at least 14 large-scale schemes in over six rivers in the country (IBRD, 2012). It is highly likely that climate change could have an impact on the realization of these schemes.

Although there is a high level of confidence in the processes linking emissions to warming, much less is known about how warming will manifest itself at the local level through changes in rainfall, runoff, groundwater recharge and climate extremes.

v. Fishery

Fishing provides 65% of the animal protein needs of the country and contributes around 3.2% to Liberia's GDP. Climate-induced changes in the biophysical characteristics together with extreme events will have significant effects on the ecosystems which support fish (especially inland) in Liberia.

A study conducted to project climate change impacts in countries with different dependencies on marine fisheries, which included Liberia, linked models of physical, biological and human responses to climate change in 67 marine national exclusive economic zones (EEZ) (Barange et al., 2014). This yields approximately 60% of global fish catches have projected that West African nations, including Liberia, may see increased production in their exclusive economic zones (EEZs) by 2050. However, the benefit of this increase in production can be fully leveraged when fisheries governance improves, and distant water fishing nations do not jeopardize local opportunities to benefit from increased productivity and the value of their fisheries. This does not translate to a lack of overall potentially negative impact on fisheries.

vi. Energy

In 2004 it was estimated that 95% of the Liberian population depends on biomass, particularly on firewood and charcoal, for cooking and heating needs and on palm oil for lighting (MoLME, 2009a). Only 2% of the rural and 10% of the urban population have access to electricity through diesel generation (GoL, 2012). The threat of climate change on the energy sector in Liberia can be explained in terms of its potential for infrastructural damage on power stations and power transmissions, as well as a barrier to access biomass fuel sources which can be caused by sea-level rise and flooding. This can also be explained in terms or the rise in temperature, particularly given that energy source in Liberia is less diversified and dominated by fossil fuel, charcoal and wood. Therefore, the energy sector in Liberia is highly sensitive to and contributes to the changing climate.

vii. Mining

The mineral sector contributed more than 65% of export earnings and approximately about 25% of Liberia's GDP prior to 1990. During the civil war, all the major mining fields were closed. During the post-war, efforts to revitalize the sector have been ongoing with the hope of using it to leapfrog the development effort of the New Liberia (MoLME, 2010). There is a need to consider the possible impact of climate change on the mining sector and the corresponding adaptation and mitigation strategies to reap gains from the effort expended be taken. The mining sector, to be climate-change smart, is important because, a) the critical inputs like energy and water can be easily affected by climate change, b) employees health can be at risk due to disease like malaria and extreme weathers, c) climate change exacerbated vulnerability will bring the mining sector in conflict with the local communities due to competition for resources such as water, d) increased risk will bring project financing to be less secure, and e) climate change will also cause physical damage on mining and communication infrastructure useful for transporting input to the mining plant and the products of the mining industry to the market (supply chain) (Julia and Ryan, n.d).

viii. Health

The Climate Change and Gender Action Plan note that average temperature across the country has been rising, which agrees with the climate analysis. This increase will continue, thereby creating the incidence of pests. It also notes that with low health standards, the correlation between temperature and waterborne diseases and the spread of malaria is an issue for concern. The population of disease-carrying mosquitoes will be boosted and will result in increased malaria epidemics, which already accounts for more than 30% of Liberian deaths (UNICEF, 2013).

Climate change could alter or disrupt natural systems, making it possible for diseases to thrive and spread. This includes those caused by water-borne pathogens (such as cholera) as well as those caused by vector-borne diseases (such as malaria, onchocerciasis, and schistosomiasis). In addition, vector-borne diseases, which have aquatic phases and changes in the pattern of rainfall –and subsequent habitat change –, will therefore also affect their epidemiology. Other climate-sensitive diseases of concern to the country include respiratory disease (such as tuberculosis) and disease associated with, or exacerbated by, malnutrition (such as HIV/AIDS) (EPA, 2013b).

ix. Transport

A large portion of the road infrastructure, which is the dominant surface for transport network for Liberia, is in the populous area (i.e. 40 miles of the coast). In this situation, it is apparent that climate change is a big threat to the infrastructure, including the road network. The climate disasters that occurred in 2007 and 2009 in Liberia displaced thousands of people, and sea erosion resulted in the devastation of several infrastructures, including roads and airports.

(https://climateandsecurity.org/2014/08/19/liberias-rising-waters/). In turn, the transport sector is considered as one of the sources of GHG emissions with regard to its energy use; and it is one of the key strategic intervention sectors considered in the Liberian INDC, including using 5% palm oil biodiesel with gasoline and diesel which is expected to have 40% reduction in GHG emission (the Republic of Liberia, 2015).

Therefore, the GoL seeks to integrate climate-smart principles together with the National Transport Master Plan, a critical move in the direction to lift the adaptation capacity of the existing road and other transport infrastructures from the current high level of vulnerability. It is expected that such action will make new transport designs, and the rehabilitation and maintenance effort become climate-smart, which will efficiently contribute to the development vision of the country.

x. Industry

The industrial sectors contribute 5.4% to Liberia's GDP and employ almost 8% of the working population. The major industries include mining, which is agriculture-based. (http://www.economywatch.com/world_economy/liberia/industry-sector- industries.html).

As in many agriculture-dominated developing countries, agro-industries and related industries are dependent on climate-sensitive resources such as rain-fed agriculture, which are relatively significant in Liberia as they constitute the bulk of the economy. The current trend of climate change, which can be explained in terms of erratic rainfall and temperature condition linked with the interconnected nature of agro-industries and agriculture sector, will imply that industries whose input depends upon agriculture will continue to be severely affected by climate change. Thus, adaptation strategies to the industrial sector in Liberia are therefore critical in this era of changing climate.

xi. Tourism

Climate is a principal source of tourism as it codetermines the suitability of locations for a wide range of touristic activities (UNEP, 2008). On the other hand, extreme weather conditions like floods, heatwaves, storms, and tropical cyclones will affect the tourism industry through infrastructural damage, additional emergency preparedness requirements, climate-induced vector-borne diseases, business interruptions, etc. It is also possible to mitigate the carbon emissions from the tourism sector through mainly change in behaviour of tourists, e.g., using non-motorized transport such as bicycles and change in technology and market mechanism.

In the face of all these opportunities, climate change has been an obstacle for the development of the tourism sector through degradation of ecosystems and infrastructure, which results in a change in tourists' preference as a holiday destination (Maria B. et al., 2006). Therefore, building resilience to climate change in the tourism sector enables maximized benefits to be obtained from the sector (UNEP, 2008).

xii. Infrastructure

Currently, Liberia's infrastructure capacity for basic social services is low and highly vulnerable to climate change. In 2005, it was projected that a rise in sea level by 1 m, would cause a loss of about 95 km2 of the estimated 565-km long coastline (due to inundation); and 50% of the area inundated (48km 2) will be areas with settlement such as parts of the capital city of Monrovia, West Point, New Kru Town, River Cess, Buchanan, and Robertsport, which are less than 1 m above mean sea level (Wiles, 2005). This was projected to result in a loss in infrastructure and land of around $250 million apart from the social and psychological stress to the population, with women and children being particularly vulnerable. The sea-level rise could also inundate the seaward portions of the remaining mangrove wetlands, which provide critical ecosystem services along the coast (Wiles, 2005). Currently, sea-level rise and coastal erosion vehave heavily impacted on communities like West Point, New Kru Town, Sinkor and Virginia, putting major infrastructures such as the JFK Kennedy Hospital, D. Tweh High School, and the Hotel Africa at risk.

xiii. Urbanization and Settlement

Liberia's population, with a growth rate of 2.1% (LISGIS, 2008) and economy coupled with a high level of urbanization has the potential to exert pressure on available resources (basic services, infrastructure, and jobs). In 2015 Liberia's urban population was projected at 49.7%. Between 2010-2015, the urban population growth rate (average annual %) for Liberia was put at 3.4% (UNDATA, 2016).

The environmental and social conditions resulting from the country's growth, together with increased competition over resources, may intensify the country's vulnerability to climate risks. Sea level rise has resulted in increased rates of inundation, storm surges, erosion and other coastal hazards that are threatening coastal settlement, resulting in a lost in infrastructure and involuntary migration in communities like West Point and Buchanan. This involuntary settlement in Liberia has also aggravated abrupt urban slum settlements along the coastal zones by people whose previous settlement is inundated by seawater or coastal degradation (Personal interview and visual observation). This situation has, in turn, aggravated urban problems such as the problem of waste management, shortage of social services such as water, sanitation, education, health, etc. as the case is in West Point, Buchanan and other areas.

Given these numerous instances of climate change impacts, risks and vulnerabilities, it is therefore important to enhance the production of climate information and effectiveness Early Warning Systems (EWS) in Liberia. This is important to ensure that the linkages between climate change, climate action and societal benefits are properly furnished with the best available climate science and data. Further, any intervention will be prompt to ensure the highest possible quality of all meteorological, climatological, hydrological and related environmental data, products and services, most especially, those supporting the protection of life and property, safety on land, at sea and in the air, sustainable economic development and protection of the environment in Liberia.

4.3 Theory of change

The Liberia meteorological and hydrological services play a crucial role in providing weather-, water- and climate-related services as one of the important mandates to build a viable economy and sustainable environment resilient to climate change. They provide public services, which serves as the direct and visible benefits to the citizens and residents of the country. Even though the gains of integrating hydromet services in the decision-making process of key sectors cannot be overemphasized, limited fiscal capacity (as discussed in Section A 12.5 of the FP) serves as a huge barrier to transforming the hydromet sector. Both meteorological and hydrological services currently suffer from a limited budget, degraded infrastructure, security issues, poor staff retention, professional staffs, and institutional capacity. There are limited prospects for significant improvement in the medium term, even with ongoing donor-supported interventions of training and equipment purchase, unless the underlining limitations are addressed.

The Climate Information Systems (CIS) project is expected to strengthen the Liberia meteorological and hydrological services to generate quality and time climate information and attenuate the annual economic and social cost of climate hazards and disasters in the country. It will bring about the transformative impact on managing current and future risks associated with weather and climate, promoting growth in climate-sensitive priority sectors including agriculture and food security, health, water resources, disaster risk reduction, transport, energy and improving the understanding of long term climate change impacts. Generating timely and relevant weather and climate services will be an important paradigm shift to help Liberia adapt favourably to the adverse impacts of climate change and variability. The theory of change (ToC) describes the causal pathways that lead to the overall impact through the project components stated:

1. Enhanced Disaster Risk Knowledge of individuals and institutions across the country
2. Enhanced Detection, Monitoring, Analysis and Forecasting of the Hazards and Possible Consequences
3. Improved warning, dissemination, and communication
4. Improved Preparedness and Response Capabilities through forecast-based financing (FBF) mechanism
5. Co-ordinated Project management and implementation across all climate information service units in Liberia

The proposed ToC for the GCF intervention explains the process of change by outlining causal linkages in the project inputs, activities, outputs, direct outcomes, and overall impact. The identified changes are mapped as a set of interrelated pathways with each pathway showing the expected outcomes in a logical relationship with respect to the others, as well as chronological flow. The fundamental elements and key indicators of this causal chain or 'theory of change' are as follows:

Inputs

The efforts toward the envisaged future climate information services require the commitment of resources as inputs. Although the primary input, as is the purpose of the proposal, is the financial resources, it is an intermediary to more direct inputs towards delivering the desired outcome. The financial resources will translate to direct inputs such as materials and goods, equipment, procurement of human resources in the form of consultants and employed personnel, workshops and training, and other related supplies. These inputs are required for all the components defined in the proposal. Further information on specific cost composition of these inputs is also presented in the proposal budget.

Activities

Once the financial resources become available to procure the stated inputs, the next stage in the ToC is to define what activities ought to be undertaken in the context of the overall project objective. The first major activity is to establish a climate information hub (CIH)in Liberia. As already intimated in the SAP proposal the hydrological and meteorological services in Liberia, as well as other climate-related agencies such as the NDMA, operate in silos. Other activities include; build hydrometeorological observation networks for numerical weather prediction and Impact-Based Forecasting (IBF) establish a disaster information management system and institute early action protocols including Forecast-Based Financing (FBF), and develop effective communication channels to deliver the climate information services produced, and provide guidelines on the implementation, evaluation and reporting standards of the project.

The KEY BENEFITS AND GOALS of FBF are:

- **Increased Efficiency -** Actors can use early warnings from forecasts to implement timely preparedness and early actions before a potential disaster occurs
- **Increased Knowledge-** Actors can anticipate the location, intensity, probability and duration of an extreme event
- **Cost-Effectiveness -** Actors can reduce the cost of future humanitarian interventions through actions that protect lives and livelihoods
- A 2018 return on investment study in Nepal on implementing the approach, found that **US$22 million** can be saved when responding to an emergency of average size (175,000 affected people). Over 20 years, **US$34** and **42kg** of CO2 emissions can be saved per dollar invested, after deducting the investment cost.
- Another 2018 USAID study on Ethiopia, Kenya and Somalia indicates that early response to drought, combined with safety net transfers and resilience-building activities, could over a 15-year period save **US$4.3 billion**, or an average of US$287 million per year.

Financial Arrangements for Forecast-based Financing in Liberia.

Forecast-based financing is embedded on an innovative mechanism with financial instruments which allow financial flows for pre-planned early actions that are triggered by forecasted climate-related hazards. FbF is embedded in an innovative mechanism with financial instruments, which allows financial flows for pre-planned early actions that are triggered by forecasted climate-related hazards.

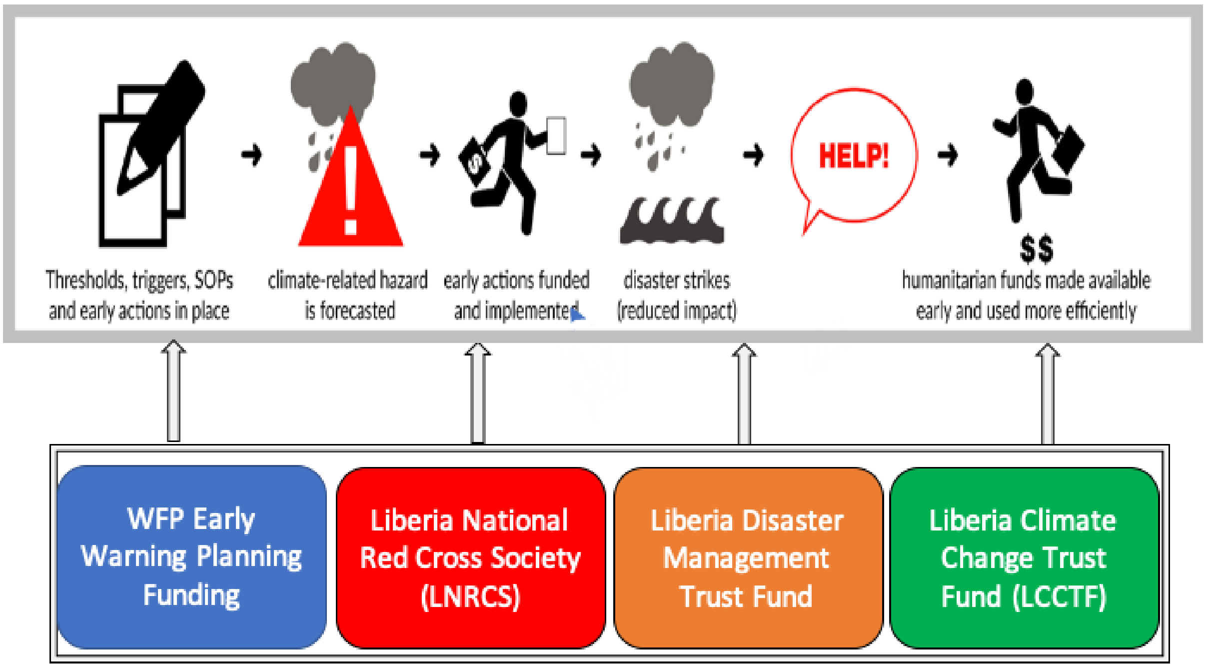


Figure 76: Financial Instruments for Forecast-based Financing in Liberia

There are two major financial instruments linked to forecast-based financing in Liberia. As indicated in Figure 42, the fund allocation from WFP and the Trust Fund set up by the Government for Disaster planning. These financing instruments also support the sustainability measures identified for the funding proposal.

(a) WFP Early Warning and Planning Funding.

The WFP allocation is tied to Outcome 3 of strategic intervention in Liberia on emergency preparedness and response and disaster risk management systems by 2030. The main objective is to strengthen disaster preparedness and management capacities in the country. As part of this component, the Government is working with WFP to set up funding and "ring-fence" for planning, financing and management of forecasted climate disasters that could affect food security and community livelihoods of particularly the vulnerable population. There are transition and exit strategies planned in consultation with communities, partners and relevant national institutions. The exit strategy includes "enhancing capacities of national and subnational institutions in the core areas of disaster management, early warning systems and information management to help with the process of progressive transfer of WFP activities to the Government. About $3 million (representing 6%) of WFP intervention in the country are allocated for the resilience planning and management, and about $1.8 million of that is allocated for cash transfers in case any of the forecasted climate disasters are triggered.

(b) The Liberia Disaster Management Trust Fund (DMTF).

The DMTF was established by Section 4.1 of June 2016 ACT TO ESTABLISH THE NATIONAL DISASTER MANAGEMENT AGENCY by the Government. The DMTF has two funding windows for (i) the Disaster Mitigation and (ii) Disaster Response. It is the financing mechanism established for sustainable financing of projects and programs to strengthen disaster preparedness, emergency response and mitigation towards the implementation of the Disaster Management Action Plan. The Disaster Mitigation Fund window is specifically intended for early warning and preparedness, including funding for planning and financing forecasted climate disasters that could be triggered.

The resource mobilization efforts to capitalize the fund include (1) national annual budgetary allocation and appropriation by Legislature; (2) special levies of fees as determined by the Government; (3) revenues from taxes as determined by the Government; (4) grants and donations from natural person, body, corporate, multilateral institution, organization or agency, or the government of any country (bilateral donors); (5) any other resources that may accrue in the course of the Agency's operation. Funds mobilized from these sources are channelled into the DMTF account with disbursements approved by the Board of Directors and signed by the Chairperson of the Board and the Executive Director of the Agency.

(c) Liberian Climate Change Trust Fund (LCCTF) established

Given the huge funding gap for climate change-related disasters response through the FbF mechanism, Liberia requires huge amount of financial support from international community and donor partners. Though domestic resources are received from government treasury, private sector and individuals, these resources are however, complementary support. Thus the need for the GCF intervention to facilitate legislative process that will speed up the establishment of the LCCTF becomes imperative.

The theory of Change (Figure 43) of the GCF project is structured as follows:

Outputs

The results of the identified inputs and the stated activities will yield specific outputs in relation to the project components. One of these outputs (Output 2.1) is expected to establish and equip operational National Climate Information laboratories. These labs, which will be established at the buildings of the LMS, LHS, and NDMA will serve the purpose for generation of climate services. The other outputs of the project include an improved and robust hydromet capacity and enhanced forecasting system, and a disaster management system and early action protocols in terms of disaster response should then be in place. Reliable and effective communication channels would have been built, and a monitoring and evaluation guideline pertaining to the project would have been scripted.

Another output (Output 4.3) will establish the Liberian Climate Change Trust Fund (LCCTF), a financial mechanism targeted at addressing climate change needs as proposed in the National Policy and Response Strategy on Climate Change document. This is will effectively promote means to finance-focused climate actions. An integrated working approach will be adopted in utilizing the funds obtained so that the objectives of the national policy and response strategy are met. Furthermore, this funding approach will address the critical adaptation responses while also considering mitigation interventions in a balanced way, so that the country will gradually strengthen the green path of development. In parallel, this fund will support enabling pillars of capacity building, technology development, transfer and the awareness-raising towards the achievement of the climate change policy and strategy objectives in Liberia. More importantly, the LCCTF will support the mobilization of needed resources to mitigate the impact of hydromet-related hazard IBF-EWS to complement the existing financial instrument established by the WFP and the DMTF established through the Act that established the NDMA. The

LCCTF will contribute to the national resource pool assigned exclusively to respond to climate-related disasters once the FbF mechanism is activated. This Fund will further be replenished with certain percentages of the cost recovery and revenue realized from climate information services offered to end-users including large-scale commercial farmers, fishing companies, aviation sector businesses, neighbouring countries such as Sierra Leone, Guinea, and Ivory Coast.

The National Climate Change Steering Committee (NCCSC) will monitor the Fund by authorizing the immediate release through the NDMA once warnings (red alerts) that activates the FbF mechanism are issued. Also, the hydromet sector will seek funding opportunities from the WMO SOFF support for GBON.

These outputs are expected to yield specific goals defined as outcomes.

Outcomes

The expected outcomes of the project are reflected in the components. The project will lead to a high institutional integration for climate information services through, an increase in the volume of climate information generated and the accuracy of the information, an increase in the readiness and early action protocols for disaster response, timely dissemination and awareness of climate information, and a continuous assessment of the impact of climate information overall.

Impact

The inputs, activities, outputs and outcomes herein outlined are all geared toward the overall objective of the project; an increased climate-resilience and sustainable development through broad and easy access to climate information and early warning systems in Liberia.

Further, This CIS project will result in a substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.

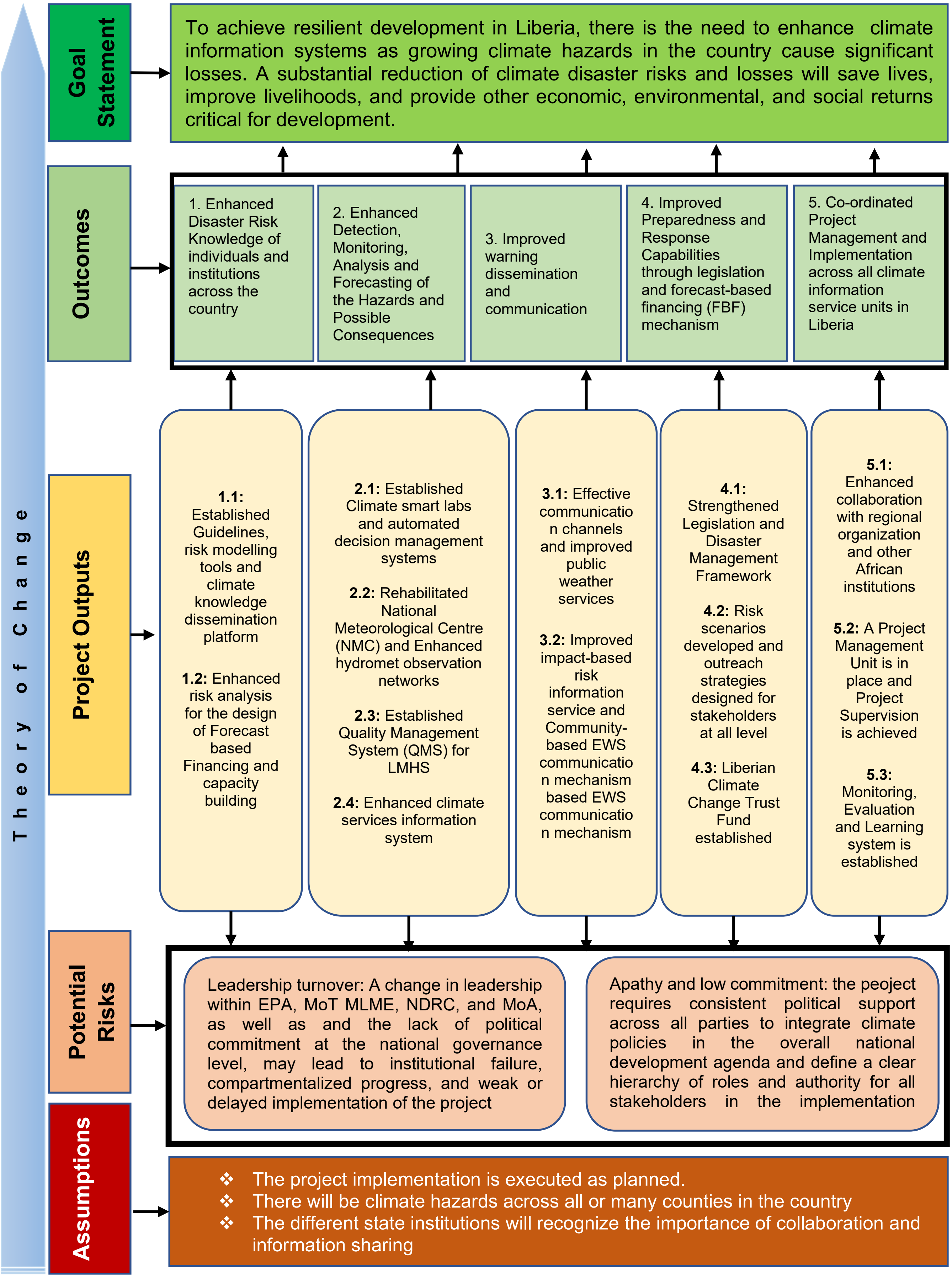

Theory of Change
Goal Statement
To achieve resilient development in Liberia, there is the need to enhance climate information systems as growing climate hazards in the country cause significant losses. A substantial reduction of climate disaster risks and losses will save lives, improve livelihoods, and provide other economic, environmental, and social returns critical for development.
Outcomes
1. Enhanced Disaster Risk Knowledge of individuals and institutions across the country
2. Enhanced Detection, Monitoring, Analysis and Forecasting of the Hazards and Possible Consequences
3. Improved warning dissemination and communication
4. Improved Preparedness and Response Capabilities through legislation and forecast-based financing (FBF) mechanism
5. Co-ordinated Project Management and Implementation across all climate information service units in Liberia
Project Outputs
1.1: Established Guidelines, risk modelling tools and climate knowledge dissemination platform
1.2: Enhanced risk analysis for the design of Forecast based Financing and capacity building
2.1: Established Climate smart labs and automated decision management systems
2.2: Rehabilitated National Meteorological Centre (NMC) and Enhanced hydromet observation networks
2.3: Established Quality Management System (QMS) for LMHS
2.4: Enhanced climate services information system
3.1: Effective communication channels and improved public weather services
3.2: Improved impact-based risk information service and Community-based EWS communication mechanism based EWS communication mechanism
4.1: Strengthened Legislation and Disaster Management Framework
4.2: Risk scenarios developed and outreach strategies designed for stakeholders at all level
4.3: Liberian Climate Change Trust Fund established
5.1: Enhanced collaboration with regional organization and other African institutions
5.2: A Project Management Unit is in place and Project Supervision is achieved
5.3: Monitoring, Evaluation and Learning system is established
Potential Risks
Leadership turnover: A change in leadership within EPA, MoT MLME, NDRC, and MoA, as well as and the lack of political commitment at the national governance level, may lead to institutional failure, compartmentalized progress, and weak or delayed implementation of the project
Apathy and low commitment: the peoject requires consistent political support across all parties to integrate climate policies in the overall national development agenda and define a clear hierarchy of roles and authority for all stakeholders in the implementation
Assumptions
The project implementation is executed as planned.
There will be climate hazards across all or many counties in the country
The different state institutions will recognize the importance of collaboration and information sharing

Figure 77: Theory of Change Framework

The project will among other support (i) the construction of climate-smart information service centre that will serve as an intermediate between the hydromet service provides and the end-users, and (ii) the transformation of service delivery to attract and retain additional recovery cost to supplement government funding and improve the remuneration of staff. It is envisioned that the income will be generated from sales of tailored products and services to target customers, even to neighbouring countries.

This innovation will bring about transformational changes in the hydromet business that will foster a significant paradigm shift in the funding and provision of hydrometeorological services in Liberia and West African region. The success of this project will be unprecedented with a notable landmark for a data-sparse region like West Africa, where investments in weather and climate enterprise are very low in most member countries. The approach will align with best practices that conform to WMO standards and regulations for providing hydromet products and services. The project will enable the scaling up of LMHS and ensure the production of valued services that can be integrated to improve outcomes in agriculture and food security, water resources management, energy production, human health and well-being, transportation and disaster risk management.

Low level of coordination among government ministries, departments, and agencies has been a major barrier to information flow in Liberia. Top management does not communicate their goals and on-going actions to their colleagues in other departments, leading to a high degree of fragmentation. This project has made coordination its first component. An institution reform that opens communication channels will be instituted to ensure that there is an open-door policy with regards to sharing and accessing climate information in order to reduce duplicity of efforts increase overall returns.

The other components of the project, from the creation of physical infrastructure to the training of manpower to execute the tasks required, through to the communication of climate information to the final end-user, are all designed to drive a change in the conventional operating standards, pioneer a new era of climate awareness across the country, and deliver high quality, purposeful, and impactful climate services that create opportunities across all the different stages of the climate product creation and utilisation.

The project pursues a change in the modus operandi of climate service agencies by centralising to decentralise. A national climate information services will exist with deep roots at the county level and agents in local communities. The local climate agents and country climate offices will become active hubs in the climate information gathering and delivery in the new dawn of improved climate information services in Liberia.

4.4 Project objective, the logic of action and components

Table 12: Project logical framework

	Description	Indicators	Baseline	Targets (mid-term)	Targets (final)	Sources and means of verification	Assumptions
				Mid-term 2030	Final 2040		
				These timelines were chosen because the project activity implementation is expected to last for five years, that is, at least until the end of 2025. While the monitoring and evaluation will provide insights on the project impact during its implementation period, the impact measured at the end of the fifth year will not truly reflect the full impact of the project due to the delayed time lapse between activity and results. 2030 will be five years after the project completion, equivalent to the project implementation timeline. 2040 will be fifteen years upon the project completion. The impact can be compared with the trend of the historical baseline of the model, which is from 2006 to 2020.			
Objective related to GCF RMF Impact Areas Impact	Reduced exposure of Liberia's communities, livelihoods, and infrastructure to climate-induced natural hazards	Change in expected losses of lives and economic assets (US$) due to the impact of extreme climate-related disasters in the project zone	Project indicators will be used to update baseline information	Beneficiaries of 1,200,000 people (50% will be females)	Beneficiaries of 2,312,400 people (50% will be females)	Climate risk assessment and Socio-economic survey	This is based on the assumption that 20% of the Liberian population will benefit from the project outputs at mid-term and 100% at the long-term if funds are being released
	A1.0 Increased resilience and enhanced livelihoods of the most vulnerable people,	A1.1 Change in expected losses of lives and economic assets (US$) due to the impact of extreme climate-	Calculation of the percentage reduction in annual monetary loss from climate hazards	There will be a continuous increment in the economic losses	At least a 25% reduction in the annual monetary losses through	At least a 75% reduction in the annual monetary losses through	There will be climate hazards across all or many counties across the country

	communities, and regions	related disasters in the geographic area of the GCF intervention	Public data related to lives loss due to natural disaster in the project area	attributable to climate hazards	climate hazards 2030	climate hazards 2040	Climate services is mainstreamed in national planning and DRR strategy
	A2.0 Increased resilience of health and well-being, and food and water security	A2.2 Number of food-secure households (in areas/periods at risk of climate change impacts)	Field Surveys Agriculture production output data	100% of food-secure households are at risk	70% of food-secured households are at risk	50% of food secure household are at risk	Climate services is mainstreamed in national planning and farmer's decision-making
	A3.0 Increased resilience of infrastructure and the built environment to climate change threats	A3.1 Number and value of physical assets made more resilient to climate variability and change, considering human benefits (reported where applicable)	EPA Assessment Report	Baseline assessment of climate hazards impact to be undertaken during year 1	At least 30% improvement in the resilience of infrastructure and built environment to climate treats	At least 70% improvement in the resilience of infrastructure and built environment to climate treats	Timely and sufficient mobilization of resources to enhance the resilience of infrastructure and built environment to climate-related treats
	A4.0 Improved resilience of ecosystems and ecosystem services	A4.1 Coverage/scale of ecosystems protected and strengthened in response to climate variability and change	EPA Assessment Report	35% of ecosystem is protected from climate variability and change			
Component 1: Enhanced Disaster Risk Knowledge of individuals and institutions across the country		# of decision support system established	Baseline study to be conducted year 1	1	1	Designed framework for hydromet services Climate-related hazard assessment report Annual performance report M & E report	Based on the assumption that the geospatial information system would have been established to provide knowledge on climate risk and impacts

Component 2: **Enhanced Detection, Monitoring, Analysis and Forecasting of the Hazards and Possible Consequences**	# of production, support, and delivery systems improved	Baseline study to be conducted year 1	0	1	Climate information reports Seasonal rainfall prediction Monthly weather and climate review	Based on the assumption that the density of observing networks would have been improved. Adequate generation of climate data and products
	# of hydromet forecasting system established	Baseline study to be conducted year 1	1	2	Climate information reports Seasonal rainfall prediction Monthly weather and climate review	Based on the assumption that the density of observing networks would have been improved. Adequate generation of climate data and products
Component 3: **Improved warning dissemination and communication**	# of community-based EWS communication mechanism established	0	1	1	Daily Public weather service Monthly climate bulletins. M & E reports	Effective and comprehensive communication of weather and climate information to people at risk
	# of Public Weather Service studio established	0	1	1	Daily weather forecast	Availability of Daily weather forecast via different media outlets
Component 4: **Improved Preparedness and Response Capabilities through forecast-based financing (FBF) mechanism**	# of legislations developed or updated (Independence of the LMS and LHS, and mobilization of resources for FbF)	0	1	3	M & E report Annual performance report (APR)	Independence of the LMHSs and sufficient funds are mobilized for FbF
	# of FbF mechanism established	0	1	1	M & E report APR	Timely and sufficient funds for the FbF

Component 5 **Co-ordinated Project management and implementation across all climate information service units in Liberia.**		# of collaboration agreement signed disaggregated by type	0	2	5	Quarterly/annual performance report	There exists good relationship with international institutions including regional organization to share data and experiences
		# of Annual Work Program and Budget approved and implemented	0	3	5	Annual Work or Budget	AWP continue to be required by the AfDB
		# of MEL systems established	0	1	1	Monitoring and evaluation report	M&E activities is carried out unhindered
		# of Annual Project Audits undertaken	0	3	5	Audit Report	Annual Audits continue to be required by the AfDB
		# of performance report report by type (APR, IPR, MTR, PCR)	0	6	9	APR, IPR, MTR, PCR	GCF continues to make use of the APR
Component 1	**Output 1.1 :** Established Guidelines, risk modelling tools and climate knowledge dissemination platform	# of standard guidelines produced on climate information in Liberia laboratory in operation	0	1	2	Annual performance report	Institutions/entities forming part of the CSIS hub will be open and cooperative in developing and implementing the guidelines.
		# of internet-based geospatial platforms established	0	1	2	Climate-related hazards Assessment report	Disaster management decision will be evidence based
	Output 1.2: Enhanced risk analysis for the design of Forecast based Financing and capacity building	# of climate hazards assessments undertaken	0	**2**	4	Climate hazard assessment reports	Improved on climate risk and associated impacts as well as the willingness to learn
		# of national databases	0	1	2	National Database	Availability of data at the country level which

							will be aggregated for national database
		# of people trained disaggregated by gender and type of training	0	50 (50% female)	100 (50% female)	M & E Report and APR	Willingness to be trained
Component 2	**Output 2.1: Established Climate smart labs and automated decision management systems**	# of operational labs/ centres for climate information services established	0	2	4	Annual Performance review report Project mid-term review report.	Implementation schedule for construct will be maintained in line with the project timelines. Land and site arrangement will be not be of challenge
		# of automated decision management system for climate services established and operationalized	0	1	1	Annual project performance review report Project mid-term review report	Decision management system is established and operational conditioned on the availability of funds
	Output 2.2: Rehabilitated National Meteorological Center (NMC) and Enhanced hydromet observation networks	# of NMC buildings refurbished	0	1	1	Annual project performance review report Project mid-term review report	Commitment to provide NMC space to be rehabilitated will be upheld by Government.
		# of hydromet observation networks enhanced	1	2	3	Project mid-term review report. Annual performance report	Maintenance and upgrade of hydromet network will be executed as per schedule
	Output 2.3 Established Quality Management System (QMS) for LMS	# of QMS established for the LMS	0	1	1	LCAA review reports	There will be a high and acceptable compliance level on QMS maintained by RIA
	Output 2.4: Enhanced climate services information system	Percentage of climate service recipients increased	5%	15%	50%	Project performance review report Survey report on access to CIS	The public will have interest in climate services

Component 3	**Output 3.1: Effective communication channels and improved public weather services developed**	# of Public Weather Service studio established	0	1	1	Daily weather forecast	Availability of Daily weather forecast via different media outlets
		% of men and women who believe that the quality and quantity of climate information has improved	0%	50%	75%	Sector specific information platform	Resources to facilitate the timely production sector specific information will be made available
	Output 3.3: Improved impact-based risk information service and Community-based EWS communication mechanism	% of men and women who believe that they are better-informed about climate hazard	0	1	1	Survey	Resources ensure that the PWS studio is functional are made available in a timely fashion
		% of men and women who find the community-based EWS effective	0	50%	75%	Survey	Targeted audience (beneficiaries) are willing to uptake the provided climate information
Component 4	**Output 4.1: Strengthened Legislation and Disaster Management Framework**	# of legislations developed or updated (Independence of the LMS and LHS, and mobilization of resources for FbF)	0	1	3	M & E report Annual performance report (APR)	Independence of the LMHSs and sufficient funds are mobilized for FbF
		# of FBF mechanism established	0	1	1	M & E report APR	Timely and sufficient funds for the FbF
	Output 4.2 Risk scenarios developed and outreach strategies designed for stakeholders at all level	Total # of documents on disaggregated climate information users and package tailored information produced	0	1	1	Annual performance report, Mid-term evaluation report Survey report on access to CIS	There will be increased interest and willingness by the public to receive early warnings
	Output 4.4: Liberian Climate Change Trust Fund established	# of Climate Change Trust Funds established	0	1	1	Annual financial report; Annual performance report, mid-term evaluation report	There will be a strong political will and support toward the establishment of the NCF

Component 5	**Output 5.1: Enhanced collaboration with regional organization and other African Institutions**	# of collaboration agreement signed disaggregated by type	0	2	5	Quarterly/annual performance report	There exists good relationship with international institutions including regional organization to share data and experiences
	Output 5.2: A Project Management Unit is in place and Project Supervision is achieved	# of performance report report by type (APR, IPR, MTR, PCR)	0	6	9	APR, IPR, MTR, PCR	GCF continues to make use of the APR
		# of Annual Project Audits undertaken	0	3	5	Audit Report	Annual Audits continue to be required by the AfDB
	Output 5.3 Monitoring, Evaluation and Learning system is established	# of MEL systems established	0	1	1	Monitoring and evaluation report	M&E activities is carried out unhindered
Activities	***List the activities.***	***Description:***				***Inputs***	
	Activity 1.1.1: *Establishment of Guidelines and risk modelling tools*	This activity will strengthen the regulatory framework for hydromet services. It entails the following (i) Development of guidelines for streamlining meteorological and hydrological information generation; and (ii) Conduct of risk modelling to assess the potential impact of climate-related hazards and accompanying losses - including lives, livelihoods, properties, and cost implications				*Consultants, materials, equipment*	
	Activity 1.2.1: *Establish an internet-based Geospatial platform*	This activity entails setting up an internet-based Geospatial platform and laboratory for national climate-hazard mapping studies. It will consist of a database and a decision support system to carry out a climate-hazard risk assessment and evaluation of optimal risk reduction alternatives related to physical planning and infrastructure.				*Consultants, materials, equipment*	
	Activity 1.2.1: climate hazards assessments, communities' consultations and national database	This activity entails setting up an internet-based Geospatial platform and laboratory for national climate-hazard mapping studies. It will consist of a database and a decision support system to carry out a climate-hazard risk assessment and evaluation of optimal risk reduction alternatives related to physical planning and infrastructure.				*Consultants, materials, equipment*	

	Activity 1.2.1: climate hazards assessments, communities' consultations and national database	This activity involves: (i) conducting a preliminary assessment of climate-related hazards and losses; (ii) community level consultation; and (iii) support for the development of a database of historical disaster impacts at NS and national level	*Professional services, consultants, materials, and equipment*
	Activity 1.2.2: Community based actions and capacity building	This activity entails: (i) Staff training and capacity building; (ii) Scale up and establish Community-Based Actions (CBATs) in the counties; (iii) Staff Training on technical services (iv) Staff Training on instrument maintenance and calibration	*Professional services and Consultants*
	Activity 2.1.1: Development and Operationalization of an automated decision management system for climate services	This activity will: (i) Develop an automated decision management system for climate services ; (ii) operationalization automated decision management system for retrieving products and services	*Professional services of firm, equipment, materials*
	Activity 2.1.2: Establishment of Meteorological and Hydrological lab with LMS and LHS	The activity will involves: (i) establishment of Meteorological lab within the LMS consisting of forecasting, observation and instrumentation, remote sensing and satellite, climatology, and agrometeorology units; and (ii) establishment of Hydrological lab within the LHS for groundwater and surface water assessment	*Training materials, consultants, equipment*
	Activity 2.1.3 : Strengthening environmental monitoring lab and enhancing NDMA emergency operations	This activity entails (i) Strengthening the environmental monitoring lab at the EPA (ii) Enhancement of the National Disaster Management Agency's emergency operations centre	*Training materials, consultants, equipment*

	Activity 2.1.4: Installing solar systems for sustainable and uninterrupted power supply	This activity calls for detailed engineering and installation of a 142 kWp solar system including storage for continuous power supply	*Professional services, Materials, equipment*
	Activity 2.2.1: NMC Rehabilitation	This entails the following: (i) rehabilitating the forecast and observing office; (ii) equipping and furnishing the rehabilitated NMC building; and (iii) establishing and equipping Central Forecasting Office (CFO)	*Professional services, Materials, equipment, consultant*
	Activity 2.2.2: Enhancing the Hydrometerorological observation networks	This activity calls for the following: (i) acquisition of new automatic weather stations and hydrological monitoring stations to strengthen existing networks; (ii) rehabilitation of damaged equipment and measuring instruments, including the satellite receiving systems Rehabilitate damaged equipment and measuring instruments, including the satellite receiving systems; (iii) procure and install a radar at the Roberts International Airport; (iv) establish Unmanned Aerial Systems (UAS) for upper air observation networks; (v) set up a facility for the operations and maintenance of hydromet infrastructure; and (vi) procure and maintain project vehicle	*Professional services, consultants, equipment, and materials*
	Activity 2.3.1: Developing good understanding of QMS, gap analysis and workplan	This includes, (i) Developing a good understanding of QMS – This activity will involve a desk review with the support of QMS experts in countries that already have implemented such a system; (ii) Preparing gap analysis and workplan	*Professional services, Consultants, materials and equipment*
	Activity 2.3.2: QMS Policy Development and policy related training	This activity will (i) Establish quality policy and quality objectives; and (ii) Training on QMS and validation of workplan	*Professional services, Equipment, materials*
	Activity 2.3.3: QMS ISO 9001 Certification	This activity will (i) Conduct internal audit; and (ii) Acquire QMS ISO 9001 certification	*Professional services, Equipment*
	Activity 2.4.1: Establishing an E-infrastructure for	This activity will (i) Establish an E-infrastructure for weather and seasonal forecasting, data, and information management ; and (ii) Build an effective support system with innovative	*Professional services, Equipment, material, consultants*

	weather and seasonal forecasting with support system	information and communications technology infrastructure for data transmission, storage, processing, quality control, and visualization	
	Activity 2.4.2: Establishment of Communities of Practice	This activity will (i) Create a community of practice (CoP) in operational numerical weather and seasonal prediction and forecasts verification; (ii) Create CoP in development, use, and management of information and e-infrastructure; (iii) LNRCS to participate in co-production of forecasts for decision making to bring user perspective, designing forecast thresholds for FbF triggers, and carrying out forecast verification to calculate the probability of acting in vain	*Equipment, materials, consultants*
	Activity 2.4.3: Production of seasonal forecasts and related trainings	This activity will involve the following: (i) Produce and validate core weather and seasonal information products for priority sectors; (ii) LNRCS and NDMA to help in the Training of LMHS staff to improve understanding of forecast needs by communities in order to develop tailored products that will be relevant and inform decision-making	*Equipment, materials, consultants*
	Activity 3.1.1: Trainings, surveys, engineering assistance and impact evaluation of dissemination measures	This activity will involve the following: (i) provide Wireless Training at the International Centre for Theoretical Physics (ICTP); (ii) Undertake site survey, on-site training, and initial deployment; (iii) provide direct engineering assistance; (iv) provide on-site Internet of Things (IoT) Training in Liberia; (v) Conduct surveys to determine ideal communication channels for different users; (vi) Conduct surveys to ascertain the reach of climate information (feedback); and (vii) Evaluate the impact of climate information based on users' response/reaction	*Professional services, Consultants, Equipment*
	Activity 3.1.2: Establishment of Public Weather Service studio	This activity will, (i) Procure and install equipment for PWS studio; (ii) Procure TV weather presentation facilities and system; and (iii) procure single size band (SSB) radio communication for staff	*Professional services, Consultants, Equipment*
	Activity 3.2.1: Delivering improved impact based risk information service	This activity will (i) Develop and implement an LHMS information portal; (ii) Monitor user assessment of services provided by LHMS institutions and organisations Monitor user assessment of services provided by LHMS institutions and organisations; (iii) 3 Undertake training in media relations to improve hydrometeorological data users experiences; and (iv) Organise six dialogues in communities vulnerable to climate risk	*Consultants, Equipment, materials*

	Activity 3.2.2: Establishing community-based EWS communication mechanism	This activity entails the following: (i) Consultation and engagement with communities on tailored early warning information through Community-based Action teams; (ii) 2 Develop communication guidance and Communication Action Response Plans (CARPs); (iii) Facilitating a Seasonal Participatory Scenario Planning; (iv) Develop IEC materials in multiple local languages and conduct CBATs in coordination with the NDMA to promote Disaster Risk Reduction awareness and behaviour change (v) Establish an Emergency operations Centre within LNRCS to facilitate receipt, analysis and dissemination of the early warning information	*Consultants, Professional services*
	Activity 4.1.1: Developing and updating legislations in order to transform LMS and LHS into a single semi-autonomous agency	This activity will (i) Formulate legislation to transform LMHSs into a semi-autonomous government agency; (ii) Facilitate regular meetings with policymakers to inform them of LHMS activities and plans as well as demonstrate the relevance of their services to socio-economic development	*Equipment, fuel and lubricants*
	Activity 4.1.2: Strengthening Liberia´s Disaster Management Framework	This activity will, (i) Develop guide to govern DRM in Liberia and also use it to benchmark the checklist on Law and Disaster Preparedness and Response (ii) Organise a national workshop with key stakeholders to share the findings of the mapping and design a roadmap to implement the recommendations (iii) Provide technical support in the revision of a Disaster Risk management instrument	*Equipment, training, materials*
	Activity 4.2.1 : Delivering on early actions, consultations and roadmaps	Activity 4.2.1 entails: (i) Collaboration with NDMA to develop SOPs for early actions; (ii) Completing a scoping study; (iii) Consultations on FbF and a national dialogue; (iv) Development of FbF Roadmaps (v) Ensure early actions are implemented at all levels the following the forecast and in the case of trigger activation	*Consultants, equipment*
	Activity 4.2.2: Dialogue, peer to peer learning, capacity building and pilot testing	This activity involves, (i) Capacity-building on FbF ; (ii)High-level dialogues; (iii) Support pilot testing and implementation of early actions for identified hazards; and (iv)Facilitate peer to peer learning	*Consultants, Equipment*
	Activity 4.3.1 : Establishment of	This activity will establish the LCCTF as a financial mechanism targeted at addressing climate change as proposed in the National Policy and Response Strategy on Climate Change document	*Travel, training, consultants*

	Liberian Climate Change Trust Fund		
	Activity 5.1.1: Facilitation collaboration and organizing study tours	This activity will (i) Facilitate LMHS collaboration with regional organisations and African institutions for the production and delivery of weather and climate services; and (ii) 2 Organize study tours of African countries with advanced NMHS;	*Consultants*
	Activity 5.2.1: Recruitment of PMU staff, Preparation of the Operational manual and Project supervision	This activity entails, (i) recruitment of the six key staff that will be responsible for implementation; (ii) Prepare the operational manual; (iii) Undertake project supervision missions; (iv) Undertake a mid-term review; and (v) Undertake a project completion mission (including supervision missions from Red Cross)	*Training materials, consultants*
	Activity 5.3.1: Monitoring, Evaluation and Learning System	Activity 5.3.1 involves: (i) Developing an MEL Plan; (ii) Preparing annual financial audit reports; (iii) Develop M&E Tools including Results Indicator Reference Sheet (RIRS), and Results Indicator Tracking Matrix (RITM); (iv) Undertake a baseline analysis; (v) Procure MEL software (vi) Undertake Data Quality Assessment (DQA); and (vii) Provide MEL training	*Training materials, consultants*
	Activity 5.3.2: Impact Evaluation	Activity 5.3.2 will, (i) Conduct an impact evaluation assessment of the project; and (ii) Prepare donor reports	*Consultant, Project team, GCF and AfDB Team*

4.5 Timeline of the implementation

Table 14: Implementation time table

	Q 01	Q 02	Q 03	Q 04	Q 05	Q 06	Q 07	Q 08	Q 09	Q 10	Q 11	Q 12	Q 13	Q 14	Q 15	Q 16	Q 17	Q 18	Q 19	Q 20
Outcome 1: Enhanced Disaster Risk Knowledge of individuals and institutions across the country																				
Output 1.1: Guidelines for streamlining meteorological and hydrological information generation are established																				
Activity 1.1.1 Establishment of Guidelines and risk modelling tools																				
Activity 1.1.2 Establish an internet-based Geospatial platform																				
Output 1.2: Enhanced risk analysis for the design of Forecast based Financing and capacity building																				
Activity 1.2.1 climate hazards assessments, communities consultations and national database																				
Activity 1.2.2 Community based actions and capacity building																				

Outcome 2: Enhanced Detection, Monitoring, Analysis and Forecasting of the Hazards and Possible Consequences																				
Output 2.1: Established Climate smart labs and automated decision management systems																				
Activity 2.1.1 Development and Operationalization of an automated decision management system for climate services																				
Activity 2.1.2 Establishment of Meteorological and Hydrological lab with LMS and LHS																				
Activity 2.1.3 Strengthening environmental monitoring lab and enhancing NDMA emergency operations																				
Activity 2.1.4 Installing solar systems for sustainable and uninterrupted power supply																				
Output 2.2: Rehabilitated National Meteorological Centre (NMC) and Enhanced hydromet observation networks																				
Activity 2.2.1 NMC Rehabilitation																				

Activity 2.2.2 Enhancing the Hydrometeorological observation networks																				
Output 2.3: Established Quality Management System (QMS) for LMS																				
Activity 2.3.1: Developing good understanding of QMS, gap analysis and workplan																				
Activity 2.3.2: QMS Policy Development and policy related training																				
Activity 2.3.3: QMS ISO 9001 Certification																				
Output 2.4: Enhanced climate services information systems																				
Activity 2.4.1 Establishing an E-infrastructure for weather and seasonal forecasting with support system																				
2.3.2 Activity 2.4.2 Establishment of Communities of Practice																				
2.3.2 Activity 2.4.3 Production of seasonal forecasts and related trainings																				
Outcome 3: Improved warning dissemination and communication																				
Output 3.1: Effective communication channels and improved public weather services developed																				

Activity 3.1.1 Trainings, surveys, engineering assistance and impact evaluation of dissemination measures																				
Activity 3.1.2 Establishment of Public Weather Service studio																				
Output 3.2: Improved impact-based risk information service and Community-based EWS communication mechanism																				
Activity 3.2.1 Delivering improved impact based risk information service																				
Activity 3.2.2 Establishing community-based EWS communication mechanism																				
Outcome 4: Improved Preparedness and Response Capabilities through legislation and forecast-based financing (FBF) mechanism																				
Output: 4.1 Strengthened legislation and Disaster Management Framework																				
Activity 4.1.1 Developing and updating legislations in order to transform LMS and LHS into a single semi-autonomous agency																				
Activity 4.1.2 Strengthening Liberia´s Disaster Management Framework																				

Output: 4.2 Risk scenarios developed and outreach strategies designed for stakeholders at all level																				
Activity 4.2.1 Delivering on early actions, consultations and roadmaps																				
Activity 4.2.2 Dialogue, peer to peer learning, capacity building and pilot testing																				
Output 4.3 Liberian Climate Change Trust Fund established																				
Activity 4.3.1. Establishment of Liberian Climate Change Trust Fund																				
Component 5: Co-ordinated Project Management and Implementation across all climate information service units in Liberia																				
Output: 5.1 Enhanced collaboration with regional organization and other African Institutions																				
Activity 5.1.1 Facilitation collaboration and organizing study tours																				
Output: 5.2 A Project Management Unit is in place and Project Supervision is achieved																				
Activity 5.2.1 Recruitment of PMU staff, Preparation of the Operational manual and Project supervision																				

Output: 5.3 Monitoring, Evaluation and Learning (MEL) system is established																				
Activity 5.3.1 Monitoring, Evaluation and Learning System																				
Activity 5.3.2 Impact Evaluation																				

5 Implementation arrangements

5.3 Stakeholders analysis and engagement plan

The results presented below reflects is an analysis of stakeholders' interests, and expectations from, and potential contribution to the Liberia climate information services. These results are not exhaustive. They are intended to inform partnerships with the stakeholders with a focus on improving meteorological services to meet their needs. The stakeholder assessment is presented in Table 15.

Table 13: Stakeholder assessment of hydrometeorological services in Liberia

Stakeholders	**Interests of stakeholders**	**Stakeholder Expectations from LMSs**	**Potential stakeholder contribution to LMS**
World Meteorological Organization	International collaboration in meteorology that includes sharing observation, data, products and relevant skills.	Annual contributions and implementation of WMO programmes.	Enhancing human resources and infrastructure through international collaboration in meteorology.
International Civil Aviation Organization, International Air Transport Association and Liberia Airport Authority	High-quality meteorological information for air transport.	Ability to provide high-quality meteorological information for air transport.	Resources from cost recovery to invest in the improvement of services.
World Health Organisation	Weather and climate information, and early warnings to support decision-making in the delivery of services	Timely, reliable and accurate weather and climate information, and early warnings to support the management of disease outbreaks and delivery of services.	Advocacy on the value of weather and climate services to the management of health activities and partnerships to enhance the infrastructure for collecting, sharing, and processing observations and data to generate products for the sector.
World Food Programme	Weather and climate information to monitor food security and to support WFP's Agrometeorological initiatives in the West African Sub-region.	Timely, reliable and accurate weather and climate information to support the monitoring of conditions that would influence food security.	Advocacy on the value of weather and climate services for food security and partnership in the improvement of services.
World Bank and African Development Bank (AfDB) and the United Nations Development Programme (UNDP)	Partnerships in enhancing the ability of society to adapt to climate change.	Weather and climate information to support the design and implementations of initiatives to enhance resilience to climate change.	Partnerships in actions to revive meteorological services in Liberia by providing resources to establish infrastructure and train human resources for providing weather and climate services.

Environmental Protection Agency	Weather and climate information to support activities to protect the environment.	Timely, reliable and accurate weather and climate information to support activities to protect the environment.	Advocacy on the value of weather and climate services for environmental protection and partnership in the improvement of services.
Liberia National Red Cross Society	Weather and climate information, and early warnings for disaster risk reduction.	Timely, reliable, and accurate weather and climate information, and early warnings to support activities for disaster preparedness and for search and rescue activities.	Advocacy and Partnerships in joint projects.
University of Liberia	Partnerships in education, training, and research.	Weather and climate data for conducting research and students for training.	Developing human resources and enhancing understanding of weather and climate processes.
Ministry of Lands, Mines & Energy, and Rural Renewable Energy Agency	Weather and Climate services to develop and operate infrastructure for power supply and investment in renewable energy, and to support safety in mining.	Timely, reliable, and accurate weather and climate forecasts, and early warnings and long historical climate information to support their activities.	Advocacy and Partnerships in the development and implantation of joint projects to improve services to the ministry and the Agency.
Ministry of Information, Culture & Tourism	Expected weather and climate conditions.	Timely, reliable, and accurate weather and climate forecasts to support the planning and management of activities in the sectors.	Advocacy on the value of weather and climate services to tourism, public safety and in improving the wellbeing of citizens-and partnerships in establishing weather observing stations.
Liberia Hydrological Service	Weather and climate information to support the design, development, and management of infrastructure for water resource management.	Historical climate data, and observations in water catchment areas.	Partnerships in gathering and sharing meteorological and hydrological data.
National Disaster Management Agency	Weather and climate information, and early warnings for disaster risk reduction.	Timely, reliable and accurate weather and climate information, and early warnings to support activities for disaster prevention, preparedness, and for search and rescue activities.	Advocacy on the benefits of weather and climate information and early warnings for disaster risk reduction and partnership in establishing infrastructure and developing the services for the sector.
Public Security Organs	Weather and climate information for maintaining the safety	Weather and climate information to support public safety activities.	Advocacy on the value of weather and climate

	of the public and for managing any threats to public safety.		services to public safety.
National Fishery Aquaculture Authority	Weather and climate information and early warning to support the safety of fisherman offshore and inland through informed decisions to prevent exposure to weather and climate-related risks.	Timely, reliable, and accurate weather and climate forecasts, and early warnings to support inland and offshore fishing activities.	Advocacy on the value of weather and climate services to the sector and partnerships in establishing weather observing stations and in developing sector-specific products.

5.4 Capacity assessment and due diligence on the executing entities

Before the conflict, the LMS had a total of twenty-eight (28) meteorological staff who provided services at the airport and to the public. The staff operated sixteen (16) climatological stations and one Agrometeorological Station. The LMS had twenty-three (23) rainfall Stations. The conflict destroyed all the stations except for one at the airport, which is still operational.

The LMS has only 11 members of staff of which only 3 are trained meteorologists' class I with at least a degree in meteorology. Apart from the station at the airport operated by the Airport Authority, the LMS does not have any stations collecting data on real-time other than the 12 AWS installed on cell phone towers that do not meet the recommended standards of WMO.

The LMS needs to re-establish the stations destroyed during the conflict, acquire data processing systems, re-establish telecommunications systems and recruit qualified personnel to be able to be operational to provide weather and climate services to the government, citizens and institutions. The LMS also needs robust dedicated internet to access information and products from advanced meteorological centres and data from other LMSs of Members of WMO to improve services. The training of staff already working for LMS is an important process to enable them to contribute to the mandate of LMS fully.

Lack of infrastructure for collecting observations, processing data and for communicating information and products to users together with inadequate skilful staff are among the factors that negatively affect the ability of LMS to take advantage of the advances in science and technology to provide high-quality services.

5.5 Implementation arrangements and governance of the project

The African Development Bank (AFDB), which is the accredited entity, will carry out this project and apply the experiences it has gained in implementing various loans and multilateral/bilateral grants. The Bank through Climate Change and Green Growth Department (PECG) and the ClimDev-Africa Special Fund (CDSF) have vast experience in managing Climate Change projects. The bank will sign a Subsidiary Agreement (SA) with the government of Liberia on behalf of the Environmental Protection Agency (EPA) of Liberia- the Executing Agency (EA) of this project.

AFDB shall oversee, supervise, manage and monitor the GCF approved project and sub projects (Implementing partners) to achieve specified objectives and results of the project.

AFDB technical and fiduciary teams shall conduct supervisory mission at least twice a year during the implementation period to ensure that the implementation of the project is in accordance with the legal agreements between the Bank and the GCF; and between the Bank and EA and co-implementing institutions. In addition, the Bank shall provide constant advice and guidance to the entities that will implement the project in terms of technical aspects, fiduciary requirements, environmental & social aspects, and monitoring & evaluation.

EPA will be the Executing Agency and serve as the Project's lead "Implementing Agency". EPA will a head a Project Implementing Unit (PIU). The PIU will coordinate the implementation of the project, and will consist of three technical departments (Liberia Meteorological Agency, Liberia Hydrological Service and National Disaster Management Agency), Project Manager and Project Staff. The role of the three technical department is to provide technical support to the PIU. The details of the implementation structure is depicted in Table 16.

Table 14: Implementation Structure with RACI Matrix

Components	Output	Activities	Responsible	Accountable	Consulted	Informed
Component1: Enhanced Disaster Risk Knowledge of individuals and institutions across the country	Output 1.1: Established Guidelines, risk modelling tools and climate knowledge dissemination platform	Activity 1.1.1: Establishment of Guidelines and risk modeling tools	EPA	EPA, LMA, LHS, NDMA	LMS, LHS	AfDB, NCCSC
		Activity 1.1.2: Establishment of internet based geospatial platform	EPA	EPA, LMA, LHS, NDMA	MGCSP MOH, WMO	AfDB, NCCSC
	Output 1.2: Enhanced risk analysis for the design of Forecast based Financing and capacity building	Activity 1.2.1: climate hazards assessments, communities consultations and national database	EPA	IFRC LNRCS RCRCCC	MGCSP, MoH, WMO	AfDB, NCCSC
		Activity 1.2.2: Community based actions and capacity building	EPA	LMHS, WMO	MGCSP MoH	AfDB Districts
Component2: Enhanced Detection, Monitoring, Analysis and Forecasting of the Hazards and Possible Consequences	Output 2.1: Established Climate smart labs and automated decision management systems	Activity 2.1.1: Development and Operationalization of an automated decision management system for climate services	EPA	EPA, LMA, LHS, NDMA	MOD,MOA, MOT, MoH/CHT	AfDB, NCCSC
		Activity 2.1.2: Establishment of Meteorological and Hydrological lab with LMS and LHS	EPA	EPA, LMA, LHS, NDMA	MOD,MOA, MOT, MoH/CHT	AfDB, NCCSC
		Activity 2.1.3 : Streghtening environmental monitoing lab and enhancing NDMA emmergency operations	EPA	EPA, LMA, LHS, NDMA	MOD,MOA, MOT, MoH/CHT	AfDB, NCCSC
		Activity 2.1.4: Installing solar systems for sustainable and uninterrupted power supply	EPA	EPA, LMA, LHS, NDMA		AfDB, NCCSC
	Output 2.2: Rehabilitated National Meterorological Center (NMC) and Enhanced hydromet observation networks	Activity 2.2.1: NMC Rehabilitation	EPA	NMC	LMA, LHS, NDMA	AfDB, NCCSC
		Activity 2.2.2: Enhancing the Hydrometerorological observation networks	EPA	EPA, LMA, LHS, NDMA	RIA	AfDB, NCCSC
	Output 2.3 Established Quality Management System (QMS) for LMS	Activity 2.3.1: Developping good understanding of QMS, gap analysis and workplan	EPA	LMA, LHS	NDMA	AfDB, NCCSC
		Activity 2.3.2: QMS Policy Development and policy related training	EPA	LMA, LHS	MOD,MOA, MOT, MoH/CHT	AfDB, NCCSC
		Activity 2.3.3: QMS ISO 9001 Certification	EPA	LMA, LHS		AfDB, NCCSC
	Output 2.4: Enhanced climate services information system	Activity 2.4.1: Establishing an E-infrastucture for weather and seasonal forcasting with support system	EPA	ICTP		AfDB, NCCSC
		Activity 2.4.2: Establishment of Communities of Practice	EPA	EPA, LMA, LHS, NDMA	MOH WMO	AfDB, WFP Districts
		Activity 2.4.3: Production of seasonal forecasts and related trainings	EPA	LMA, LHS	MIA	AfDB, NCCSC
Component3: Improved warning dissemination and communication	Output 3.1: Effective communication channels and improved public weather services	Activity 3.1.1: Trainings, surveys, engineering assistance and impact evaluation of dissemination measures	EPA	ICTP		AfDB, NCCSC
		Activity 3.1.2: Establishment of Public Weather Service studio	EPA	EPA, LMA, LHS, NDMA		AfDB, NCCSC
	Output 3.2: Improved impact-based risk information service and Community-based EWS communication mechanism	Activity 3.2.1: Delivering improved impact based risk informtion service	EPA	IFRC LNRCS RCRCCC		AfDB, NCCSC
		Activity 3.2.2: Establishing community-based EWS communication mechanism	EPA	IFRC LNRCS RCRCCC	MGCSP MOH WMO	AfDB Districts
Component4: Improved Preparedness and Response Capabilities through legislation and forecast-based financing (FBF) mechanism	Output 4.1: Strengthened Legislation and Disaster Management Framework	Activity 4.1.1: Developping and updating legislations in order to transform LMS and LHS into a single semi-autonomous agency	EPA	EPA, LMA, LHS, NDMA	MIA	AfDB, NCCSC
		Activity 4.1.2: Strengthening Liberia´s Disaster Management Framework	EPA	EPA, LMA, LHS, NDMA		AfDB, NCCSC
	Output 4.2 Risk scenarios developped and outreach strategies designed for stakeholders at all level	Activity 4.2.1 : Delivering on early actions, consultations and roadmaps	EPA	WFP	Districts, NDMA	AfDB, NCCSC
		Activity 4.2.2: Dialogue, peer to peer learning, capacity building and pilot testing	EPA	WFP		AfDB, NCCSC
	Output 4.3 Liberian Climate Change Trust Fund established	Activity 4.3.1 : Establishment of Liberian Climate Change Trust Fund	EPA	EPA, LMA, LHS, NDMA	MoF	AfDB, NCCSC
Component5: Co-ordinated Project Management and Implementation across all climate information service units in Liberia	Output 5.1: Enhanced collaboration with regional organization and other African Institutions	Activity 5.1.1: Facilitation collaboration and organizing study tours	EPA	EPA, LMA, LHS, NDMA		AfDB, NCCSC
	Output 5.2: A Project Management Unit is in place and Project Supervision is achieved	Activity 5.2.1: Recruitment of PMU staff, Preparation of the Operational manual and Project supervision	EPA	EPA, LMA, LHS, NDMA	AfDB MGCSP MOH WMO	IFRC LNRCS RCRCCC
	Output 5.3 Monitoring, Evaluation and Learning system is established	Activity 5.3.1: Monitoring, Evaluation and Learning System	EPA	EPA, LMA, LHS, NDMA	MGCSP	AfDB,NCCSC
		Activity 5.3.2: Impact Evaluation	EPA	EPA, LMA, LHS, NDMA	MGCSP	AfDB,NCCSC

NDMA: National Disaster Management Agency	MoA: Ministry of Agriculture
LMS: Liberia Meteorological Service	LMA: Liberia Metrological Agency
LHS: Liberia Hydrological Service	RCRCCC: Red Cross Red Crescent Climate Change
EPA: Environmental Protection Agency	NCCSC: National Climate Change Steering Committee
MoT: Ministry of Transport	MGCSP: Ministry of Gender, Children and Social Protection
NCCS: National Climate Change Secretariat	MoH/CHT: Ministry of Health /County Health Team
RIA: Roberts International Airport	MIA: Ministry of Internal Affairs
MOD: Ministry of Defense	

The partnering agencies IFRC LNRCS and the Red Cross Red Crescent Climate Centre, which will implement specific project activities, will be known as “Implementing Partners”. The Implementing Partners will sign sub agreements with EPA. EPA will review and monitor Implementing Partners” work & financial plan, procurement plan, M&E plan, among others.

The IFRC, LNRCS and the Red Cross Red Crescent Climate Centre will develop the impact based forecasting methodology for Forecast based Financing as well as ensuring that the last mile is reached through designing activities that address the needs of those at most risk of the climate hazards. They will support the establishment of community early warning systems, promote their connection to national early warning systems and enable an effective forecast-based financing (FbF) mechanism, to ensure climate-informed decision-making, planning, and response by and for the communities most at-risk from climate shocks and extreme weather events.

The African Development Bank (AFDB), which the Accredited Entity (AE), will carry out this project and apply the experiences it has gained in implementing various loans and multilateral/bilateral grants. The AFDB has vast experience in managing Climate Change projects, and over the last three years, it has implemented climate change projects worth over 3 million dollars in Liberia.

According to the Accreditation Master Agreement, the African Development Bank will enter into a Funded Activity Agreement with the Green Climate Fund. Additionally, AFDB will carry out the project by signing a single Subsidiary Agreement with the government of Liberia representing the Environmental Protection Agency (EPA) of Liberia- the Executing Entity (EE) of this project.

AFDB shall oversee, supervise, manage and monitor the GCF approved project. AFDB technical and fiduciary teams shall conduct supervisory mission at least twice a year during the implementation period to ensure that the implementation of the project is in accordance with the legal agreements between the Bank and the GCF; and between the Bank and EE. In addition, the Bank shall provide constant advice and guidance to the entities that will implement the project in terms of technical aspects, fiduciary requirements, environmental & social aspects, and monitoring & evaluation.

EPA as the Executing Entity, will head a Project Implementing Unit (PIU). The PIU will coordinate the implementation of the project, and will consist of three technical departments (Liberia Meteorological Agency, Liberia Hydrological Service and National Disaster Management Agency), Project Manager and Project Staff. The role of the three technical department is to provide technical support to the PIU.

Other institutions/ agencies in the project which will support EPA to implement the project i.e. IFRC (including LNRCS and the Climate Centre), will be known as “Responsible Parties. IFRC will sign Memorandum of Understanding (MoU) with EPA. EPA will review and monitor their work & financial plan, procurement plan, M&E plan, among others.

The IFRC, LNRCS and the Red Cross Red Crescent Climate Centre will develop the impact based forecasting methodology for Forecast based Financing as well as ensuring that the last mile is reached through designing activities that address the needs of those at most risk of the climate hazards. They will support the establishment of community early warning systems, promote their connection to national early warning systems and enable an effective forecast-based financing (FbF) mechanism, to ensure climate-informed decision-making, planning, and response by and for the communities most at-risk from climate shocks and extreme weather events.

The National Climate Change Steering Committee (NCCSC) will be responsible for project oversight at the national level. NCCSC will consists of representatives from all collaborating government and international institutions. At the level of NCCSC, there will be a quarterly inter-ministerial meeting to discuss the progress of the project and other climate-related issues.

A Vulnerability and Adaptation Expert Working Group will be constituted. This inter-sectoral working group consisting of personnel from LHS, LMS, MoT, NDMA, LCAA, MOA, Ministry of Gender, Children and Social Protection (MGCSP), MoH, and WMO will convene monthly to discuss progress and implementation-related issues.

The project will establish a Climate Information Service Labs to coordinate the activities of hydromet service producers. The CIS Labs will provide vital products on hydrology, meteorology, aviation, disaster risk reduction, and M&E. The CIS Labs will serve as a one-stop-shop for the weather, water, and climate products and other relevant environmental services. The information generated will be communicated via the most effective and efficient channel to the county, district and community levels through their respective coordination and engagement structures (i.e. committees). The information will also be shared with the international collaborating partners including the IFRC, WMO, and others working on climate adaptation and disaster response such as the USAID and the UNDP.

At the county level, the working group membership is comprised of county level representation from Ministry of Agriculture (MOA), Ministry of Transport (MOT), National Disaster Management Agency (MDMA), Environmental Protection Agency (EPA), Ministry of Health County Health Team (MoH/CHT), Ministry of Internal Affairs (MIA), Ministy of Gender, Children and Social Protection (MGCSP), Ministry of Defense (MOD), Fire Service, IFRC/LNRCS and NGOs. The county workgroup is responsible for the dissemination of the information received in a timely manner to the district level working groups and onward to the communities, where the information can be used to make evidence-based decision-making.

The district-level working group comprises district officers from MOA, MGCSP, EPA, MoH, MIA, MDMA, LNRCS and community-based organizations such as farmer cooperatives. At community level, local structure including leadership and engagement modalities such as town-hall/community meetings will be utilized. Community actors such as community chair, women and youth, persons with disabilities, development committees, farmer cooperatives are very essential. The project implementation arrangement is presented in Figure 44.

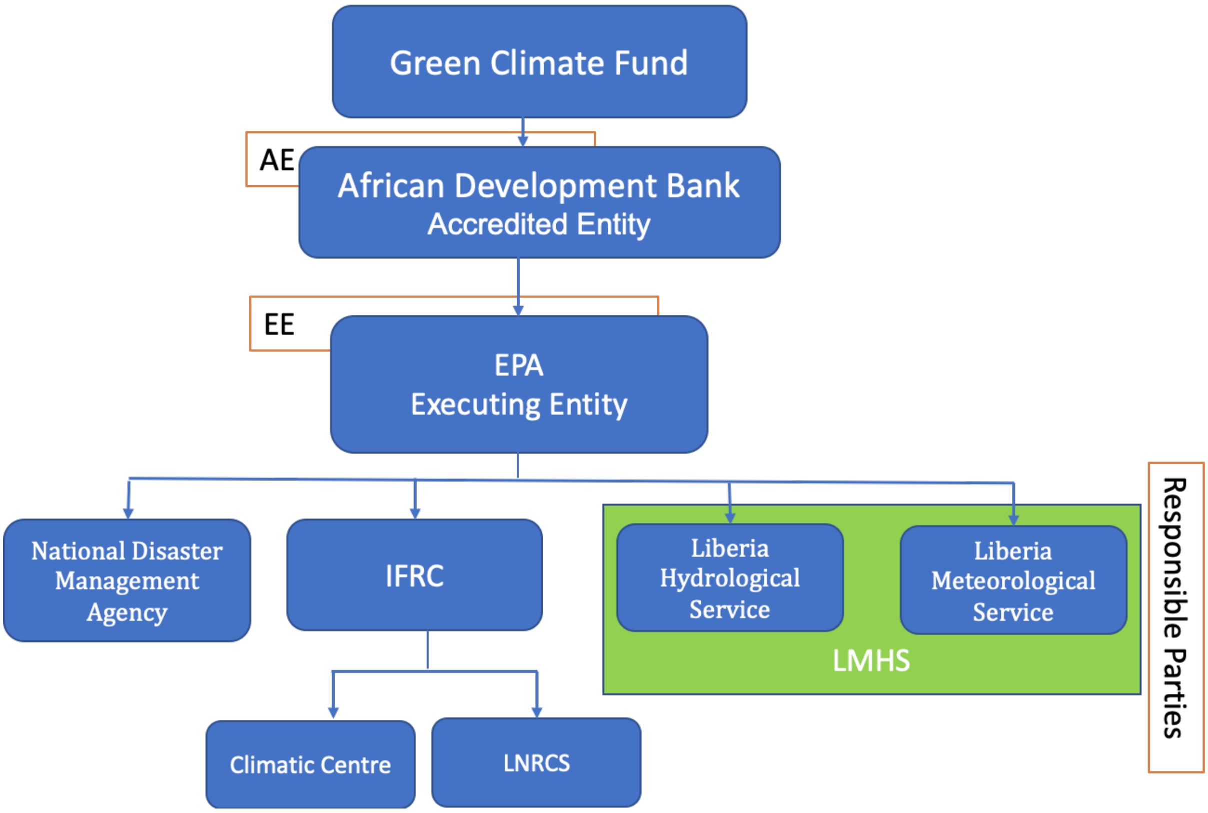


Figure 78: Project implementation arrangement

Implementation of the proposed LCCTF

The LCCTF proposed under Output 4.3 will be setup by the GoL as stated in the National Policy and Response Strategy on Climate Change document. The fund requested from GCF will be used to initially capitalize the Trust Fund. This Fund will be used to effectively promote means to finance-focused climate actions and to address the critical adaptation responses while also considering mitigation interventions in a balanced way that will strengthen the green path of development. The LCCTF will contribute to the national resource pool assigned exclusively to respond to climate-related disasters such as the FbF mechanism, which will be implemented by the NDMA in collaboration with the LNRCS and IFRC. The LCCTF will be replenished with certain percentages of the cost recovery and revenue realised from climate information services paid for by corporate organizations and end-users including large-scale commercial farmers, fishing companies, aviation sector businesses, neighbouring countries such as Sierra Leone, Guinea, and Ivory Coast.

For the implementation of the abovementioned activities, GCF will transfer the project funds of US$10,000,000 to the GCF Account at AfDB, in its capacity as an Accredited Entity. As trustee of the GCF Account, AfDB will make the GCF Proceeds, in the form of a grant, available to the Executing Entity in accordance with the terms and conditions consistent with the Funded Activity Agreement. AfDB will conclude a financing agreement with the Government of Liberia (GoL), represented by the Liberia Environmental Protection Agency (EPA), on the management and use of the funds. All disbursements under the grant will be carried out in accordance with AfDB's Grant Disbursement Handbook[24]. The PMO will receive and verify claims for payments from contractors,

[24]https://www.afdb.org/sites/default/files/documents/financial-information/disbursement_handbook_english_version.pdf

suppliers and service providers, and consolidate and approve the requests for payment and will forward a request for disbursement to AfDB. AfDB will pay the key suppliers, service providers and contractors via direct payment. An imprest account will be established in a local commercial bank acceptable to AfDB for smaller items of expenditure of the PMO and the payment of PMO staff salaries and office operating costs. AfDB, in its role as the AE, has overall responsibility and oversight for the project in line with its Accreditation Master Agreement.

The description of the flow of funds is presented in Figure 45. The funding requested for this SAP proposal is non-reimbursable proceeds. The GCF will transfer through the Trustee approved proceeds to AfDB after the FAA effectiveness, and all conditions met for disbursement. AfDB will create a special account for GCF proceeds to undertake funded activity as approved by the GCF Board. AfDB will sign the grant agreement with the Ministry of Finance (MOF) on behalf of the government of Liberia. The MOF and the Executing Agency (EPA) will open a Special account for the management of the project's administrative expenses for small purchases such office suppliers, payment for project staff, and expenses for supervision, monitoring and reporting. There will be a minimum of three signatories for checks and withdrawals for small administrative expenses. Large procurements such as the acquisition of automatic weather stations will be made directly by the AfDB to suppliers and service providers upon submission of relevant completion documents. Procurement will follow AfDB procurement procedures. The Project Steering Committee will oversee the utilization of funds with clear MOUs between the EPA as EE and the implementing partners.

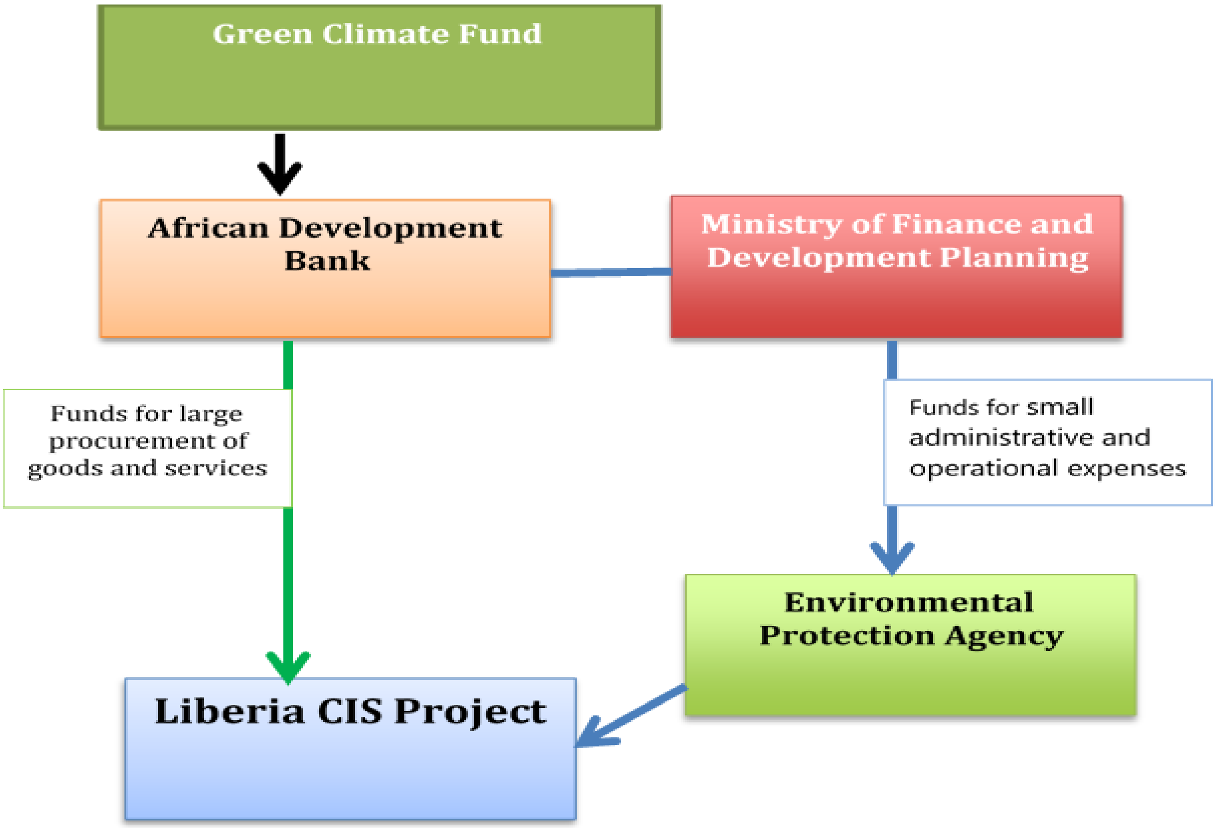


Figure 79: Flow of funds

6 Recommendations

This project is a remedy for Liberia's climate challenges. It will help create an appropriate adaptation mechanism for various climate risks and reduce the level of exposure of the major economic sectors to climate hazards. The project will also help reduces the social impact of climate through information dissemination to help people at the local level understand the implications and coping strategies of climate elements.

Furthermore, the project aligns with the strategic plan of the meteorological and hydrological services. These include;

a) A revived and operational LMS to provide high-quality weather and climate information, products and early warnings;

b) Improved access to weather and climate information, products and early warnings;

c) Improved relevance of weather and climate information, products and early warnings;

d) Enhanced partnerships in improving weather and climate information, products and early warnings;

e) Liberia Meteorological Service is transformed into an Agency; and

f) Enhanced resource mobilization.

g) Enhanced proper land resources planning and management

h) Efficient and proper disposal of solid and liquid wastes

i) Established (and/or strengthen) appropriate bodies responsible for water resources management (especially a central, national water resources authority)

j) Developed and enhanced human resources and technological capacities

k) Foster international cooperation in the management of internationally shared river basins

l) Ensured efficient means of domestic water supply (and sanitation and hygiene)

m) Integrated sustainable development and the management of water resources for all sectors, such as to guarantee socio-economic growth

n) Protected (and conserve) water resources (including wetlands)

o) Allocated water resources equitably and fairly (using appropriate and acceptable allocation principles and rules)

p) Prevented (and mitigate) natural disasters, incl. the effects of climate change.

References

Annamalai, H., Hamilton, K., Sperber, K. R. (2007). The South Asian summer monsoon and its relationship with ENSO in the IPCC AR4 simulations. Journal of Climate, 20(6), 1071-1092.

ARPEGE AGCM, and future changes. Climate Dynamics 35, 75-94.

Barange, M., Merino, G., Blanchard, J. L., Scholtens, J., Harle, J., Allison, E. H., and Jennings, S. (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. Nature Climate Change, 4(3), 211-216.

Bayol, N. and J. Chevalier (2004). Current State of the Forest Cover in Liberia: Forest Information Critical to Decision Making (June 25, 2004).

Brandolini, G.V. and Tigani, M. (2006) Liberia environmental profile. Report for the European

Caminade, C., Terray, L. (2010). Century Sahel rainfall variability as simulated by the

Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., ... Wehner, M. (2013). IPCC AR5 (2013) Chapter 12: Long-term Climate Change: Projections, Commitments and Irreversibility. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Pp. 1029-1136). Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.024

MCoolidge, HJ (1930) Climate of Liberia, Monthly Weather Review, July 1930, 291-292.

DAI (2008) Liberia Environmental Threats and Opportunities Assessment (ETOA). Final Report to USAID/Liberia, Office of Economic Growth. Development Alternatives International, Bethesda, MD.

Dieterich, C., Schimanke, S., Wang, S., Väli, G., Liu, Y., Hordoir, R., Höglund, A. and Meier, M., 2013. *Evaluation of the SMHI coupled atmosphere-ice-ocean model RCA4-NEMO*. SMHI.

Douville, H., 2002: Influence of Soil Moisture on the Asian and African Monsoons. Part II: Interannual Variability. J. Climate, 15, 701–720.

Eckstein, D. et al. (2017). "Global climate risk index 2018." Germanwatch, Bonn.

Environmental Protection Agency (EPA) (2013b). Liberia Initial National Communication, Liberia, Monrovia.

EPA (2007) National Report on the Marine and Coastal Environment In Liberia. Report to the Abidjan Convention .

Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, P. Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason and M. Rummukainen, 2013: Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Forestry Development Authority (2006). National Forestry Policy and Implementation Strategy. Liberia, Monrovia.

Gatter, W. (1997). Birds of Liberia. Yale University Press, New Haven.

Government of Liberia (GoL) (2012). Government of Liberia 2012 Sustainable Development Report. Liberia, Monrovia.

Grodsky, S., Carton, J.A. (2001) Coupled land/atmosphere interactions in the West African Monsoon. Geophysical Research Letters 28, 1503-1506.

Hagos, S. M., & Cook, K. H. (2007). Dynamics of the West African monsoon jump. *Journal of Climate*, *20*(21), 5264–5284. https://doi.org/10.1175/2007JCLI1533.1

International Bank for Reconstruction and Development (IBRD) (2012). Options for the Development of Liberia's Energy Sector. The World Bank Group. Oct. 2011. Washington, D.C, USA.

IWMI (2010). "IDIS-Integrated Database Information System." Retrieved November 2010, from http://dw.iwmi.org/IDIS_DP/query.aspx.

Janicot, S, Harzallah A, Fontaine B, Moron V (1998) West African Monsoon Dynamics and Eastern Equatorial Atlantic and Pacific SST Anomalies (1970–88). J. Climate, 11, 1874–1882.

Janicot, S., Mounier, F., Hall, N.M.J., et al. (2009) Dynamics of the West African Monsoon. Part IV: Analysis of 25–90-Day Variability of Convection and the Role of the Indian Monsoon. Journal of Climate 22, 1541–1565.

Janicot, S., Sultan, B. (2001) Intra-seasonal modulation of convection in the West African Monsoon. Geophysical Research Letters 28, 523-526.

Joly, M., Voldoire, A. (2010) Role of the Gulf of Guinea in the inter-annual variability of the West African monsoon: what do we learn from CMIP3 coupled simulations?" International Journal of Climatology 30, 1843-1856.

Joly, M., Voldoire, A., Douville, H., Terray, P., Royer, J.F. (2007) African monsoon teleconnections with tropical SSTs: validation and evolution in a set of IPCC4 simulations. Climate Dynamics 29, 1-20.

Julia N.; Ryan S. (n.d.). Adapting to Climate Change: A Guide for the Mining Industry. Retrieved from www.bsr.org/adaptation.

Kreft, S. et al. (2013). "Global climate risk index 2014." Who suffers most from extreme weather events: 1Á31.

Laprise, R.R.D.E., De Elia, R., Caya, D., Biner, S., Lucas-Picher, P.H., Diaconescu, E., Leduc, M., Alexandru, A. and Separovic, L., 2008. Challenging some tenets of regional climate modelling. *Meteorology and Atmospheric Physics*, *100*(1-4), pp.3-22.

Lavender, S.L., Matthews, A.J. (2009) Response of the West African Monsoon to the Madden–Julian Oscillation. Journal of Climate 22, 4097–4116.

Liberia Institute for Statistics & Geo-Information Services (LISGIS) (2008). Population & Housing Census. Monrovia: LISGIS. Liberia, Monrovia.

Liberia Institute for Statistics and Geo-Information Services (2008) National Population and Housing Census (2008)

Liberia National Adaptation Programme of Action (2008)

LISGIS (2010) Statistical Bulletin. Vol 2 No. 1. Liberia Institute of Statistics and Geo-Information Services. Monrovia.

Maria Berrittella, Andrea Biganoa, Roberto Rosona, Richard S.J. Tol. (2006). A general equilibrium analysis of climate change impacts on tourism. ELSEVIER, Tourism Management 27 (2006) 913– 924.

Matthews, A.J. (2004) Intraseasonal variability over tropical Africa during northern summer. Journal of Climate 17, 2427–2440.

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environment and urbanization, 19(1), 17-37.

McSweeney, C., New, M., Lizcano, G., Lu, X. (2010) The UNDP Climate Change Country Profiles. Bulletin of the American Meteorological Society 91, 157-166.

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J., ... van Vuuren, D. P. P. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change, 109(1–2), 213. https://doi.org/10.1007/s10584-011-0156-z

Ministry of Agriculture (MoA). (2015) Food and Agricultural Policy and Strategy, Monrovia.

Ministry of Land Mines and Energy (MoLME) (2009a). National Energy Policy: An Agenda for Action and Economic and Social Development. Liberia, Monrovia.

Ministry of Land Mines and Energy (MoLME) (2009b). Water and Sanitation Policy. Liberia, Monrovia.

Ministry of Land Mines and Energy (MoLME) (2010). Mineral Policy of Liberia, 2010. Liberia, Monrovia. Liberia.

Mournier, F., Janicot, S., Kiladis, G.N. (2008) The West African Monsoon dynamics. Part III: the quasi-biweekly zonal dipole. Journal of Climate 21, 1911–1928.

MPEA (2008) Liberia's vision for accelerating economic growth. A development corridor desk study. Ministry of Planning and Economic Affairs, Monrovia.

Panitz, H.J., Dosio, A., Büchner, M., Lüthi, D. and Keuler, K., 2014. COSMO-CLM (CCLM) climate simulations over CORDEX-Africa domain: analysis of the ERA-Interim driven simulations at 0.44 and 0.22 resolution. *Climate dynamics*, *42*(11-12), pp.3015-3038.

PreventionWeb (2014). "Basic Country Statistics and Indicators (2014)." from https://www.preventionweb.net/countries/lbr/data/.

Ramsar (2010). "The Ramsar sites database: Liberia." Retrieved October 19, 2010, from http://ramsar.wetlands.org/Database/AbouttheRamsarSitesDatabase/tabid/812/languag e/e n-US/Default.aspx.

Republic of Liberia (2004). Liberian National Biodiversity Strategic Action Plan. Monrovia (LNBSAP). Republic of Liberia, Monrovia.

Republic of Liberia (2015). Intended Nationally Determined Contributions (INDC).

Roehrig, R., Bouniol, D., Guichard, F., Hourdin, F. and Redelsperger, J.L., 2013. The present and future of the West African monsoon: A process-oriented assessment of CMIP5 simulations along the AMMA transect. *Journal of Climate*, *26*(17), pp.6471-6505.

Rummukainen, M., 2010. State-of-the-art with regional climate models. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), pp.82-96.

Taylor, C.M., Saïd, F. Lebel T. (1997) Interactions between the land surface and mesoscale rainfall variability during HAPEX-Sahel. Monthly Weaver Review 125, 2211–2227

Tumbey, A. (2015). Analytical research on climate change impacts on key sectors in Liberia. Environmental Protection Agency of Liberia (Unpublished Report).

UNDATA (2016). Liberia Country Profile. http://data.un.org/CountryProfile.aspx?crName=liberia. (Accessed 18/01/2016)

UNEP (2008). Climate Change Adaptation and Mitigation in Tourism Sector-Framework, Tools and Practices.

UNICEF (2013), https://www.unicef.org/wcaro/wcaro_liberia_fact_CP_malaria, (Accessed on 20/01/2017)

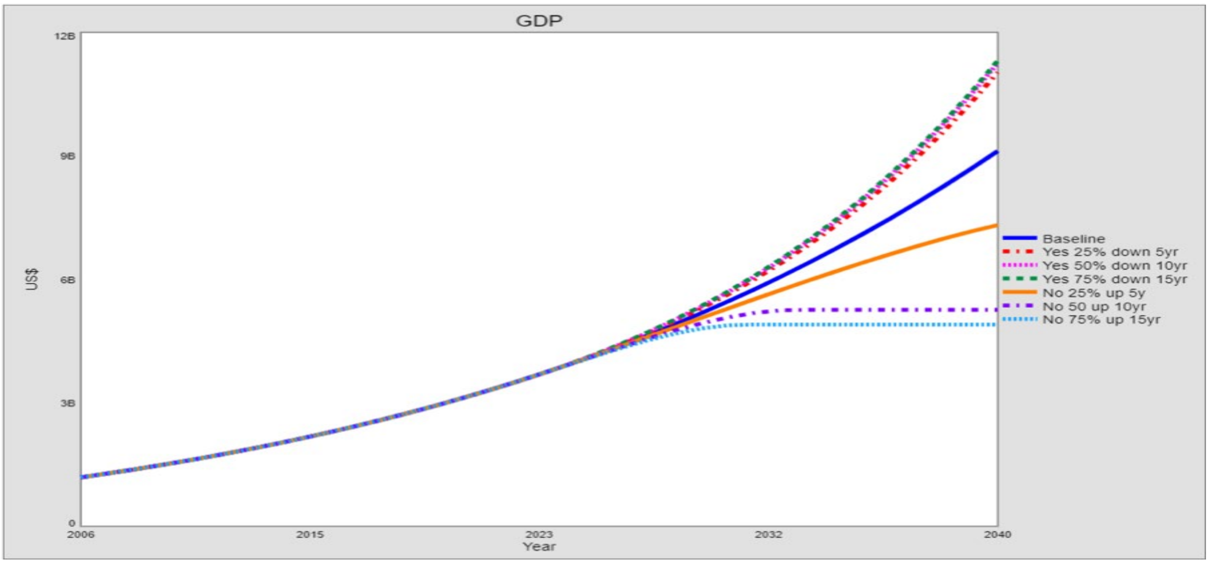
Wiles, D. L. (2005). Coastal zone vulnerability and adaptation to climate change in Liberia. In Training Workshop on Adaptation and Vulnerability to Climate Change, Maputo, Mozambique.

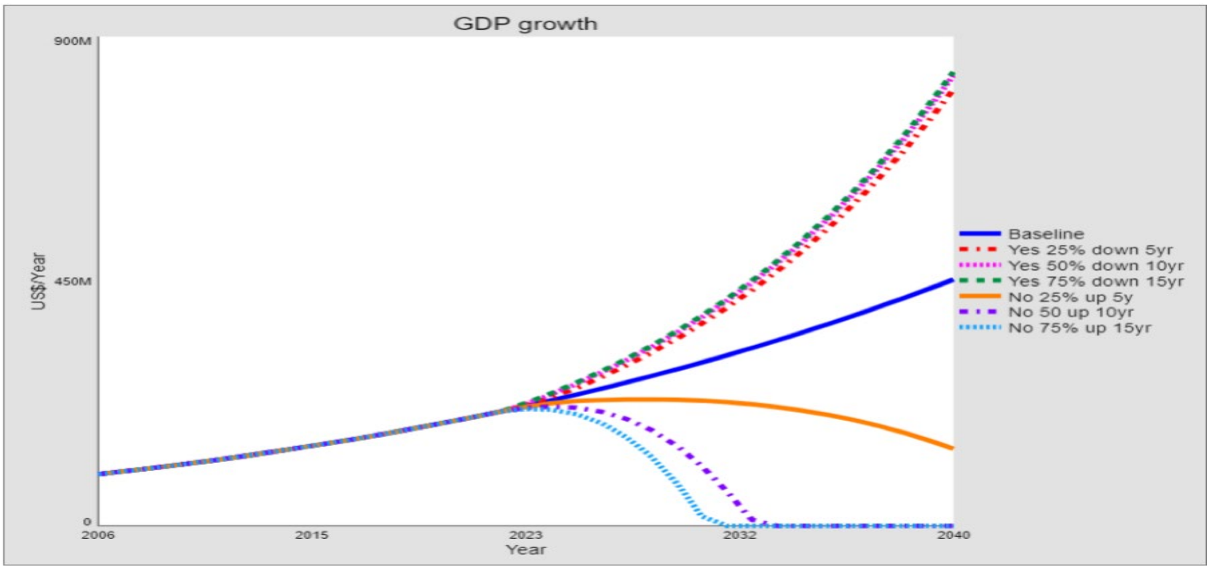
Appendices

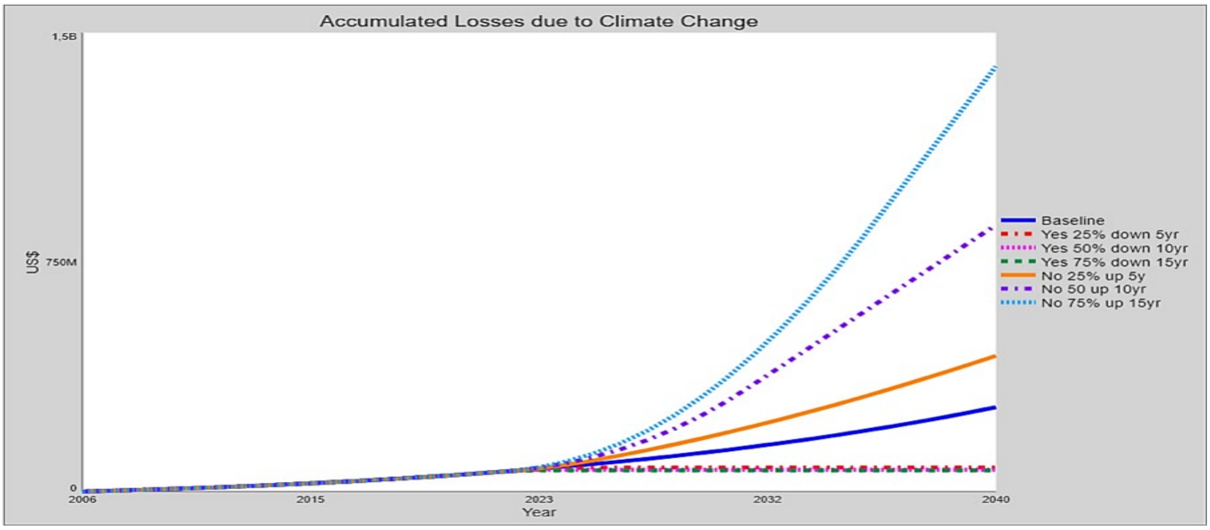
Appendix A

	Period of change			Annual Losses due to climate (in US$)						
Scenarios **(change in fractional GDP Loss)**	5 years (2021-2025)	10 years (2021-2030)	15 years (2021-2035)	2006	2019	2021	2025	2030	2035	2040
Baseline				2,566,000	6,171,000	6,554,000	8,764,000	11,527,000	14,948,000	18,236,000
25% loss increase	x			2,566,000	6,171,000	6,554,000	17,452,000	22,090,000	26,438,000	29,276,000
25% loss decrease	x			2,566,000	6,171,000	6,554,000	0	0	0	0
50% loss increase		x		2,566,000	6,171,000	6,554,000	30,407,000	57,035,000	57,845,000	57,845,000
50% loss decrease		x		2,566,000	6,171,000	6,554,000	0	0	0	0
75% loss increase			x	2,566,000	6,171,000	6,554,000	41,085,000	83,318,000	112,720,000	112,720,000
75% loss decrease			x	2,566,000	6,171,000	6,554,000	0	0	0	0
					People impacted by climate hazard annually					
Baseline				6,825	9,408	9,643	10,911	12,344	13,966	15,416
25% loss increase	x			6,825	9,408	9,643	21,821	24,689	27,933	30,832
25% loss decrease	x	X		6,825	9,408	9,643	0	0	0	0
50% loss increase		X		6,825	9,408	9,643	38,187	67,894	76,816	84,790
50% loss decrease		x		6,825	9,408	9,643	0	0	0	0
75% loss increase			X	6,825	9,408	9,643	51,825	104,927	160,615	177,289
75% loss decrease			X	6,825	9,408	9,643	0	0	0	0
					Per Capita Income					
Baseline				376	656	680	803	934	1,070	1,183
25% loss increase	X			376	656	680	800	895	946	950
25% loss decrease	x			376	656	680	807	973	1,198	1,431
50% loss increase		X		376	656	680	796	840	753	682
50% loss decrease		X		376	656	680	810	984	1,218	1,460
75% loss increase			x	376	656	680	793	794	702	636
75% loss decrease			X	376	656	680	811	987	1,223	1,467

Appendix B


GDP
12B
9B
6B
3B
0
US$
2006
2015
2023
2032
2040
Year
Baseline
Yes 25% down 5yr
Yes 50% down 10yr
Yes 75% down 15yr
No 25% up 5y
No 50 up 10yr
No 75% up 15yr


GDP growth
900M
450M
0
US$/Year
2006
2015
2023
2032
2040
Year
Baseline
Yes 25% down 5yr
Yes 50% down 10yr
Yes 75% down 15yr
No 25% up 5y
No 50 up 10yr
No 75% up 15yr


Accumulated Losses due to Climate Change
1,5B
750M
0
US$
2006
2015
2023
2032
2040
Year
Baseline
Yes 25% down 5yr
Yes 50% down 10yr
Yes 75% down 15yr
No 25% up 5y
No 50 up 10yr
No 75% up 15yr