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LIBERIA
CLIMATE CHANGE ASSESSMENT

March 2013

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Cover Graphic: Photo montage; from upper left and clockwise, oil pam planting in coastal savannah; farmstead; charcoal mound ready to light; Fanti fishing boat off coast near Monrovia. Photos courtesy of John Stanturf.

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ACRONYMS

AOGCM	Atmosphere-Oceans General Circulation Models	IBA	Important Bird Areas
BNF	Bureau of National Fisheries	IEE	Initial Environmental Examination
CAADP	Comprehensive African Agricultural Development Programme	IPCC	Intergovernmental Panel on Climate Change
CBO	Community-Based Organizations	IPM	Integrated Pest Management
CC	Climate Change	IPCC	Inter-Governmental Panel on Climate Change
CCM3	Community Climate Model version 3	ITCZ	Intertropical Convergence Zone
CDCS	Country Development Cooperation Strategy	IUCN	International Union for the Conservation of Nature
CEA	Country Environmental Analysis	LHS	Liberian Hydrological Service
CEC	Cation Exchange Capacity	LISGIS	Liberia Institute of Statistics and Geo-Information Services
CEPF	Critical Ecosystem Partnership Fund	LME	Large Marine Ecosystem
CFM	Collaborative Forest Management	MLME	Ministry of Lands, Mines and Energy
CI	Conservation International	MOFA	Ministry of Food and Agriculture
CITES	Convention on International Trade of Endangered Species	NAP	National Action Programme
CPUE	Catch Per Unit of Effort	NEPAD	New Partnership for Africa's Development
CMIP3	Coupled Model Intercomparison Project phase 3	NDPC	National Development Planning Commission
CSO	Civil Society Organization	NGO	Non-Governmental Organization
CSP	Country Strategic Plan	NRM	Natural Resources Management
EEZ	Exclusive Economic Zone	NTFP	Non-Timber Forest Products
ENSO	El Niño Southern Oscillation	PA	Protected Area
EPA	Environmental Protection Agency	PCA	Principal Component Analysis
ETOA	Environmental Threats and Opportunities Assessment	PET	Potential Evapotranspiration
EU	European Union	PGRC	Plant Genetic Resources Centre
FAO	Food and Agriculture Organization, UN	RAMSAR	Convention on Wet Lands, Ramsar Iran
FAA	Foreign Assistance Act	RCM	Regional Climate Model
FASDEP	Food and Ag. Sector Development Policy	REDD	Reduced Emissions from Deforestation and Degradation
FDA	Forest Development Authority	REDD+	REDD including sustainable forest management, conservation, and enhancement of forest carbon stocks
FtF	Feed the Future (USAID multi-year strategy)	TES	Threatened and Endangered Species
FY	Fiscal Year	UNCCC	United Nations Convention on Climate Change
GCMs	Global Circulation Models	UNCCD	United Nations Convention to Combat Desertification
GDP	Gross Domestic Product	UNDP	United Nations Development Program
GEF	Global Environment Facility	USAID	U.S. Agency for International Development
GFTN	Global Forest Trade Network	USDA	United States Department of Agriculture
GIS	Geographic Information System	USFS	United States Forest Service
GoL	Government of Liberia	WCRP	World Climate Research Programme
GSBA	Globally Significant Biodiversity Areas	WWF	World Wildlife Fund
HDI	Human Development Index	WMO	World Meteorological Organization

ACKNOWLEDGEMENTS

Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were downscaled 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).

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SUMMARY

Post-conflict Liberia faces myriad development challenges: establishing the rule of law, rebuilding infrastructure, re-invigorating the mining, rubber, timber, and agricultural export sectors. In terms of the population of Liberia, however, the greatest challenge is the condition of rural subsistence farmers. Nevertheless, the opportunity for the citizens of Liberia is rebuilding the country to be resilient in the face of climate change. Seizing this opportunity will be difficult in the current scarce-data environment as most of the information that existed prior to the civil wars was lost. To assist the Government of Liberia, the USAID-Liberia Mission tasked the US Forest Service International Programs to develop climate data, future climate projections, and assess climate vulnerability. The following summarizes the findings of the USFS team.

CLIMATE

Liberia's climate can be described in terms of two separate climate regimes: the equatorial climate regime restricted to the southernmost part of Liberia, where rainfall occurs throughout the year, and the tropical regime dominated by the interaction of the Inter-tropical convergence zone (ITCZ) and the West African Monsoon. Liberia's coastal location allows the southwesterly flow of the monsoon to prevail most of the year, maintaining a thin layer of moist marine air near the surface, although the Harmattan Wind typically intrudes for brief periods during the winter in coastal areas (duration typically less than two weeks). This interaction of the ITCZ with the monsoon flow produces the characteristic summer wet season/winter dry season of a tropical climate.We approached climate modeling in four ways: ensemble projections for three representative areas (Monrovia, Nimba, and Sapo National Park), statistical down-scaling for the entire country, dynamic down-scaling for the entire country, and a constructed aridity index for examining the effects of climate change on social and natural systems.

Representative Areas

Most Global Climate Models (GCM) have difficulty correctly reproducing a number of key features of the atmospheric circulation patterns over West Africa, contributing to the uncertainty in estimates of future rainfall. For this reason we 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. Expected changes in temperature and precipitation by 2050 and 2080 for Monrovia, Nimba, and Sapo National Park are based on an ensemble of 16 models. The general trends are for a warmer and wetter climate in most of the country. The most conservative estimates on temperature change have 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).

The ensemble predictions of precipitation in Liberia lack any sense of consistency. For example, forecast changes in precipitation in Monrovia range from 36% decreases 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% decreases 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.
The spatial pattern of temperature change is illustrated by the mean high and low daily temperatures that 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.

Statistical Downscaling

To provide a glimpse of the potential changes in the spatial pattern of precipitation, we used output from the National Center for Atmospheric Research (NCAR) Community Climate Model version 3 (CCM3) that was statistically downscaled to a 1-km resolution. Historical weather data from WMO meteorological stations in the surrounding countries were used in the statistical downscaling. Statistical projections of February average maximum temperatures indicated an increase of 1°-2° C increase throughout most of the country. The spatial pattern of temperature change is illustrated by the mean high and low daily temperatures that 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 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.

The spatial pattern of average annual precipitation currently versus 2050 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) 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. July brings the start of the mid-dry 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 northern part of country, implying a shift in the pattern of the rainy season. 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.

Dynamic Downscaling

Overall the dynamic downscaling projects a warmer and wetter climate for Liberia. Results from the dynamic downscaling indicate slightly stronger warming of just over 3^{o} C along a band paralleling the coast. Average minimum temperatures for February did not show any significant warming which is in sharp contrast with the statistical downscaling that showed a 2^{o} C increase in nighttime temperature along the coast in the west and the northeastern border area. During the wet season (May to August) the statistical downscaling indicated increases rainfall focused along the coast with inland regions experiencing normal to slightly reduced rainfall. 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. The weaker initial monsoon flow in May, allows 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. July brings the start of the mid-dry period.

Because of the complexity of correctly reproducing a number of key features of the atmospheric circulation patterns over West Africa, projections of rainfall by climate models are mixed and uncertain. Our ensemble modeling projections of rainfall among three representative meteorological stations 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 dynamics 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.

Aridity Index

Aridity is a numerical indicator of the degree of dryness of the climate at a given location and can be used to identify regions that suffer from a deficit of available water which could impair the agricultural productivity of an area. The United Nations Environment Programme defined aridity as the ratio of precipitation to potential evapotranspiration. To examine the potential impact to vegetation of these competing factors an aridity index was created as the ratio of precipitation to evapotranspiration. Note that for the statistical downscaling this ratio was multiplied by 100 to yield an integer index and for the dynamic downscaling the more traditional decimal form of the aridity index is used.

According to the projected change in the aridity index calculated using the statistical downscaled climate data, there are four areas in Liberia that will be “drier” (more arid) by 2050. The most negative values are a region from Grand Cape Mount (except right at the coast) through River Cess, Montserrado and coastal Margibi (including Monrovia). Another region stretches from east to west beginning in southeast Grand Bassa, River Cess, west Sinoe to River Gee counties. Two other clusters have only slightly negative values, one in Gbarpolu and another in Nimba. Much of the change in the aridity index is caused by higher temperatures, especially at night.

The dynamic downscaling produces smaller changes in the annual aridity than the statistical down scaling 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. Unlike the statistical downscaling, no areas of major drying (decreased average annual aridity index) were produced by the dynamic downscaling.

SOCIAL SYSTEMS VULNERABILITY

The starting point in developing an understanding of the potential vulnerability of the population to climate change and to begin to develop adaptation strategies is the current condition of the population. We utilized past survey data and the 2008 census to develop a social vulnerability index that could be displayed spatially. Most rural households are food insecure, meaning that they lack access at all times of the year to sufficient, safe, and nutritious food to meet their dietary needs; nationally, 80% of the rural population was either moderately vulnerable (41%) or highly vulnerable (40%) to food insecurity The Social Vulnerability Classification was constructed from 18 spatially referenced variables based upon county-level 2008 census data or other reports. Our analysis of social vulnerability focused on 12 social attributes at the district level from census data including: Displaced Population, Distance to Improved Drinking Water, Distance to Medical Facility, Illiterate Population, Households not involved in Fishing, Households Lacking Furniture, Households with no Livestock, Households Lacking a Mattress, Households with no Poultry, Substandard Housing, Unimproved Drinking Water Source, and Unimproved Sanitation; and 6 specified only at the county level: Dependent Population, Disabled Population, Undernourished Population, Prevalence Stunted Children, Without Access to Free Health Care/Drugs and Without Access to Land. The first step in the analysis was a principle component analysis (PCA) based on the correlation matrix to determine to what degree the dimensionality of the dataset could be reduced by taking advantage of the likely inter-relationship among the various social traits. We retained 7 principal components which accounted for 77% of the variance expressed by the original 18 social traits. We then used factor analysis to construct vulnerability classes.

The first 5 factors account for the majority of the variance explained by the seven factors and are the most easily interpreted. Factor 1 can be thought of as a “water quality” factor due to the strong influence of the Unimproved Drinking Sources and Unimproved Sanitation traits. Factor 2 reflects “food quality” as it is dominated by the three possible protein sources. Factor 3 reflects “food quantity” as its strongest traits are percentage of population under-nourished and prevalence of stunted children. Factor 4 reflects the added stress on local resources by “displaced populations.” Factor 5 groups disabled and dependent populations and reflects a stress on local resources that differs from that of Factor 4.

The overall social vulnerability of each district was classified through a cluster analysis of the seven factors identified above. The goal of the cluster analysis was to derive some broad characterization of social vulnerability to facilitate discussion. Cluster 1 shows perhaps the strongest overall vulnerability as it shows the most positive scores for among the seven factors with maximum values for Factor 3 (food quantity) and Factor 6 (access to land/free medical care). Water quality and food quality (Factors 1 and 2) also had positive scores, as did Factor 7 (lack of furniture/mattress). Displaced and dependent populations (Factors 4&5) were not found to be critical in Cluster 1.

Overall vulnerability (Cluster 1) is greatest in Lofa, Bong, Grand Cape Mount, and Bomi Counties. Cluster 3 is generally the least vulnerable group as its centroid is negative for all factors except Factors 6 and 7 which are driven by access to land/free medical and lack of furniture/mattress. Cluster 3 is comprised of Montserrado and Grand Cru Counties. Cluster 4 reflects another very vulnerable group, scoring highest in areas of displaced and dependent populations (Factors 4 and 5) and having positive values for all factors except for Factor 1. Vulnerability is therefore high in River Gee and districts in the northern half of Maryland County. Food quantity (Factor 3) is a concern in Cluster 5 (districts in Grand Bassa, River Cess, most of Sinoe and Gbarpolu, and portions of Margibi, Nimba and Grand Gedeh Counties) but this might be for differing reasons than in Cluster 1 as the factor loading for availability of protein (Factor 2) is much lower suggesting the possibility that in these districts the issue is more about food quantity than quality. Cluster 2 is most strongly influenced by Factor 1, reflecting the potential importance of water quality to districts in Nimba, Grand Gedeh, Margibi, southern part of Gbarpolu, and mostly urban areas of Sinoe and Maryland Counties.

Combining the aridity change (based on statistical downscaling) with social vulnerability indicates where the strongest climate change effects may be found. Clusters 1 and 4 were the most potentially vulnerable populations and people in Grand Cape Mount and Bomi Counties will experience the most climate change.

NATURAL SYSTEMS VULNERABILITY

Most natural resources are climate-sensitive; plant and animal species are sensitive to weather extremes, and communities are broadly distributed along climatic gradients. Soil resources are less sensitive to climate extremes but develop over time within a climatic regime characterized by mean values. Thus, climate variability and change potentially could affect these resources and the human communities that depend upon them. We examined resource vulnerability at the national level in terms of current stressors, primarily development pressure on forests and protected areas, overfishing, and climate hazards such as higher temperatures, altered rainfall patterns and sea-level rise. Climate change impacts on natural forested ecosystems, especially protected areas, are exacerbated by short-term stresses from development activity. Many of these stressors manifest throughout the country (e.g., heat stress) but some, such as coastal erosion, are limited to one region. Similarly, some resource systems are impacted by most stressors but in different ways depending on the resource subsystem, such as agriculture (e.g., small holder versus commercial operator). Assessing the vulnerability of natural systems in Liberia is made difficult by the lack of current data. We examined agriculture, forests, fisheries and coastal systems using such data as were available.

Agriculture

Rural Liberians depend upon two main crops, rice and cassava. Protein comes primarily from bushmeat and fish. Various regional projections suggest that rice will be neagatively impacted by higher temperatures, even if precipitation is adequate. Upland rice, the predominant cropping system, will be impacted by changes in seasonality of precipitation. Cassava, on the other hand, is adapted to high temperatures, drought and erratic rainfall. Current plant breeding programs aim to address the direct impacts of climate change on crop growth and the indirect effects of increased incidences of pests and diseases. Getting improved varieties to farmers will require improved extension delivery systemns and available financing.

Effects of climate change on agricultural production are the most likely in the interior counties of Bong, Lofa, and to a lesser extent Nimba. These were the primary agricultural areas before the conflict; these areas are the most likely to experience higher temperature maxima and altered rainfall patterns under the projected future climate.

Forests

The remaining areas of high forests in Liberia have been targeted by the government of Liberia for development. It is not clear that the current structure or resources of the Forest Development Authority can provide adequate oversight to guide sustainable development of the forestry resource. Even without direct exploitation for timber extraction, other development plans place the remaining biodiversity rich forests at risk from conversion to oil palm plantations and by minerals development. Projected development corridors will fragment the remaining contiguous forest. Increased access to the remaining forested areas, especially in the southeastern counties, will open them up for an influx of farmers, leading to a general drying of the forests, increased risk of degradation from wildfire from escaped agricultural burning, as well as increased exploitation for bushmeat exports to neighboring countries. A high degree of geographic overlap exists between mineral deposits and exploration permits and the protected area-forest reserve network. If exploitation occurs within these areas as expected, the potential to significantly affect biodiversity and forest cover should be considered extreme. Forest destruction and wildlife poaching will be locally extensive and permanent. Other potential environmental impacts include among others: siltation of reservoirs and rivers, ground and surface water pollution, and habitat fragmentation. The impact of over 100,000 artisanal miners operating in Liberia, including 6,000 in Sapo National Park alone, may have individually insignificant effects on biodiversity and tropical forests but cumulative effects are significant. Further, development of the transportation corridors will open up previously inaccessible areas to commercially-oriented farming and in-migration from surrounding countries.

Even though projections of precipitation change are too model-dependent to say that climate change will impact tropical forests in Liberia directly, the change in aridity may indicate where forests are most at risk from the combined effects of human disturbance and climate change. The change in aridity (from statistical downscaling) indicates the forest in eastern Liberia are the most likely area to be impacted by the “drier” climate in 2050.

Fisheries

Fisheries, both marine and freshwater, provide protein for many Liberians. Climate change impacts on the Liberian fishery will occur through a variety of direct and indirect pathways whose importance will vary depending on the type of ecosystem and fishery. Climate projections also indicated sea-surface temperatures will increase in Liberian waters with potentially negative implications for the dynamic and critical link between timing and intensity of the coastal upwelling and fishery productivity. Inland fisheries, particularly important for small-scale artisanal fishers in Liberia and an integral part of Liberian rural livelihood and food security systems could be severely impacted. Nearly the entire inland fishery lies in the Southern Upper Guinea Aquatic Ecoregion. About 20% of the 151 fishes from the ecoregion are endemic. Nevertheless, so little is known about the inland fishery in terms of rates of exploitation, diversity and status of fishes exploited, number of fishers, and state of the aquatic ecosystem that projections of climate change impacts on this important national resource are virtually impossible beyond broad generalizations. Precipitation and evapotranspiration changes, including an increase in extreme events (e.g., exacerbated floods, extreme drought), could affect inland waters causing changes in magnitude and timing of high and low river flows. These kinds of hydrological variability could adversely affect fish habitats, reproduction, growth, recruitment, and mortality.

Projections of change to the marine fishery are likewise premised primarily on generalization because of a lack of information on that resource. Severe climate change in conjunction with overfishing is projected to have significant impacts on the world's marine fisheries with estimated losses of 50% of current gross revenues of about $US 80 billion/yr. This could result in billions of dollars of lost income by fishing households with serious economic, social, and food security ramifications. The most prominent effect of climate change on marine productivity and ultimately the fishery could be increased sea temperatures even though the primary proximate driver of productivity, the upwelling system, which is temperature dependent, is admittedly complex and certainly not totally understood. Changes in sea temperature and hence upwelling strength and timing could affect primary (phytoplankton) and secondary (zooplankton) production which in turn could dramatically increase or decrease the abundance of pelagic fishes and their predators. Other projected changes in marine systems involve acidification and expansion of hypoxic zones.

Coastal Areas

Coastal ecosystems are at risk from sea-level rise, with projected increases over the next century from less than 1 m to over 2 m. In addition to the general rise in mean sea level, storm surge will impact most urban areas of Liberia. The combined effects of on-going coastal erosion and climate change induced sea-level rise in Liberia are for the most part uncertain. Even so, obviously the highest risk will be for infrastructure and associated facilities located close to the coast or low-lying coastal lagoons or river estuaries. Historic shoreline rates of change in complex and dynamic large-scale coastal systems, like the currently eroding coastline of Liberia, cannot be assumed to continue into the future. Recent acceleration in sea-level rise due to global warming is evident and at the upper boundary (worst-case) of initial projections. With the expectation that sea-level rise will continue for centuries, future coastal recession can generally be expected to accelerate relative to the recent past.

Liberia has a 565-km long coastline, and an estimated 95 km^2 of land along the coast of Liberia would be inundated if sea level rises 1 m. Under a scenario of a 1-m rise in sea level about 50% (48 km^2) of the total land loss due to inundation will be the sheltered coast. For example, parts of the capital city of Monrovia, West Point, New Kru Town, River Cess, Buchanan, and Robertsport will be lost because much of those areas are <1 m above mean sea level. Likewise seaward portions of the remaining mangrove wetlands will be lost. About $250 million worth of land and infrastructure will also be lost. Others using various global climate models project a sea-level rise in Liberia of 0.13-0.56 m by the 2090s relative to the sea level from 1980-1999.

Sea-level rise could threaten ecologically, economically, and culturally important mangrove forests in Liberia. Mangroves grow along most of Liberia‘s coast line and estuaries, situated along the boundary between land and sea with water depth following tidal cycles. Because mangroves provide important habitat (e.g., spawning and nursery areas) for food fishes and shellfishes, loss of mangroves from sea-level rise could adversely impact artisanal lagoonal fisheries in Liberia. When mangrove forests are lost or degraded local fish catches generally decline. Mangroves also provide many ecological goods and services for Liberia’s coastal communities. Reduction in area of the mangrove wetlands could result in a loss of buffering capacity from violent storm surges; increased coastal erosion; exacerbated terrestrial flooding; reduced supplies of coastal timber, fuelwood, fish smoking wood, and artisanal medicinals; and affect ground water recharge and hence, freshwater supplies.

INTRODUCTION

BACKGROUND

The Liberia USAID Mission has embarked on a consultative process to achieve four critical objectives in advancing natural resource management in Liberia. These objectives include 1) raising the profile of Liberia's natural resource assets, especially forests in national level planning exercises, with a focus on livelihood benefits and climate change impacts; 2) effectively planning for upcoming USAID investments in improved forestry management, biodiversity conservation, and response to climate change over the next five years; and 3) implementing a vulnerability assessment to better plan future climate change interventions. In furtherance of these goals, USAID-Liberia, in cooperation with the US Forest Service deployed a multidisciplinary team from the Southern Research Station, Forest Service Research and Development to conduct a climate change assessment. The field team was comprised of Dr. John Stanturf, Research Ecologist (Soils and Silviculture), Dr. Scott Goodrick, Research Meteorologist (Meteorology and Climatology), and Dr. Mel Warren, Research Aquatic Ecologist (Fisheries Biology and Aquatic Ecology). They were supported by Ms. Christie Stegall (Forestry, GIS specialist) and Mr. Marcus Williams (Meteorologist, Climate Modeler).

The objective of this Climate Change Assessment was to analyze vulnerabilities of natural resources of Liberia in the context of USAID climate change programs. The Team gathered and analyzed existing documentation (reports, policies, maps) with an emphasis on spatially explicit data. The African continent is among the most likely to suffer adverse impacts of climate change because of vulnerable social and natural systems (Dixon et al., 2003), multiple interacting stresses, and low adaptive capacity (Boko et al., 2007). In most of Africa, climate is a key driver of food security (Gregory et al., 2005; Müller et al., 2011). In much of sub-Saharan Africa, precipitation is inherently variable from year to year. This is often expressed as recurrent drought and periodic flooding. Because most agriculture is rain-fed and rural populations in many countries lack resources to moderate or adapt to drought (Dixon et al., 2003), the agricultural sector is particularly vulnerable to climate change (Haile, 2005).

We focused on characterizing current resource conditions, identifying current trends and planned development, and characterizing current climate and climate drivers. This report presents the background and current condition of resources in forestry, agriculture, fisheries, mining, and energy and examines how they may be impacted by a changing climate. We briefly describe the physical, biological, and social attributes of Liberia. Social vulnerability and adaptive capacity of key population segments was assessed, both from climate change and from policy responses to climate change.

We first modeled current and future climate to 2060 using statistical down-scaling from Global Circulation Models (GCM) incorporating weather data from the World Meteorological Organization (WMO) reporting stations in surrounding countries. These results were presented in a preliminary report in 2012 (Stanturf et al., 2012). Subsequent modeling using dynamic downscaling provided better spatial resolution of important climate features and these data are used in this report. Because of the greater computing resources required for dynamic down-scaling, the future climate projection only goes to 2030. We mapped vulnerability of social systems and examined stresses on natural systems from available data. We constructed an aridity index to spatially display projected climate change and used map overlays to highlight populations and natural resources at risk from climate change.

Assessing the potential effects of climate change in Sub-Saharan Africa is particularly challenging due to the limited information available on current climate and natural resources. Nevertheless such assessments are needed to guide development investments by government agencies and international donors. A critical limitation to our work was the general lack of credible data for most resource sectors and most importantly, a nearly complete lack of weather data specific to Liberia, a result of the collapse of governance and institutions during the civil war. Data that existed prior to the conflict was lost although some data unknown to us may exist outside the country in library and personal collections.

GENERAL SETTING

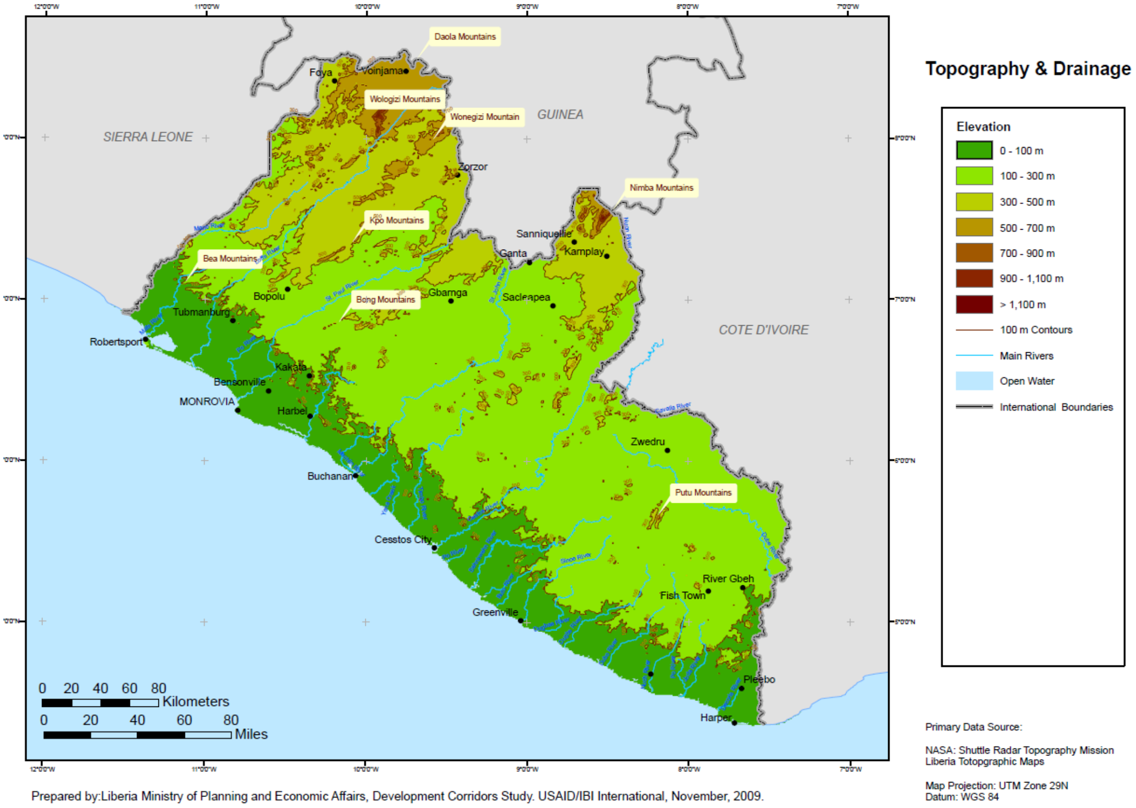
The Republic of Liberia, a relatively small country (111,369 km^2), is located entirely within the humid Upper Guinean Forest Ecosystem in West Africa on the Atlantic Coast. In terms of land area, Liberia is the fifth smallest country on the African Continent. The extreme southeast of the county is closer to the equator than any other coastal part of West Africa. Liberia is closer to the South American Continent than any other African State, being about 1,600 km from Brazil (Wiles 2005).

Liberia is located at latitudes 4°21'N and 8°33' north of the equator and longitudes 11°28'W and 7°32'W. Within its borders, 15,050 km2 consist of water, and the remaining 96,319 km2 are land. The perimeter of Liberia is 2,551 km (UNDP 2006), and it shares a border with three countries. Côte d'Ivoire is to the east with a shared border length of 598 km; Sierra Leone is to the west with a shared border of 370 km; and Guinea is to the north with a shared border of 540 km (Wiles 2005). Liberia is bordered to the south by the North Atlantic Ocean with the coastline extending 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 km2, extending 370.4 km (200 nautical mi) seaward from shore. The width of the continental shelf is generally limited by the 100 m isobath, being wider off central Liberia. The major sea ports are Monrovia, Montserrado County, and Buchanan, Grand Bassa County (Wiles 2005).

ENVIRONMENTAL SETTING

Physiography

Four physiographic regions, corresponding largely to increasing elevation, are apparent in Liberia . All the physiographic regions roughly parallel the coast: the Coastal Plain, the Rolling Hills, the Mountain Ranges and Plateaus, and the Northern Highlands (Gatter 1997).



Prepared by:Liberia Ministry of Planning and Economic Affairs, Development Corridors Study. USAID/IBI International, November, 2009.

Primary Data Source:

NASA: Shuttle Radar Topography Mission
Liberia Totopgraphic Maps

Map Projection: UTM Zone 29N
Datum: WGS 84

Figure 1 Topography and drainage of Liberia.

Sea, Coast, and Coastal Plain.—The Atlantic Ocean surface waters of Liberia lie between the Canary Current area to the northwest and the Benguela Current area to the east and are uniformly warm (26–28°C) and of 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). The area of the continental shelf adjacent Liberia is between 17,715 to 18,400 km^2, and the shelf ranges in width from 16 to 56 km (Ssentongo 1988). In the northwest the slope starts at 300 m depth but it starts at 100–120 m depth in the southeast and beyond this depth the sea floor has canyons and rocky outbreaks which limit trawling.

The Coastal Plain, lying at sea level to about 30 m in elevation (average elevation about 15 m above mean sea level) varies from 16-40 km in width. The Coastal Plain coast is about 560 km long and is formed by a powerful pounding surf with sand bars and long beaches that consist of a nearly unbroken sand strip, salt and freshwater lagoons, and a few promontories like Cape Mount (329 m elevation, at Robertsport, Grand Cape Mount County), Cape Mesurado (91 m, at Monrovia, Montserrado County), and Cape Palmas (31 m, at Harper, Maryland County) (Gatter 1997; EPA 2007). Because of the steepness of the shoreline, about 90% of the coast consists of a narrow, 20-30 m wide, sandy beach; the beach widens to 60-80 m from about King William's Point to Grand Cess in eastern Liberia. Only about 10% (60 km) of the coastline has rocky outcrops. Immediately behind the beach in 80% of the shoreline is forest, forest-like formations, or thickets. Tidal influence extends inland in wetlands and rivers to about 10 km (20 km in the Junk River) (Gatter 1997).

Although no offshore islands or natural harbors exist along the coast, rocky reefs and cliffs occur locally (Gatter 1997). Rivers generally flow slowly over the coastal plain in large meanders, widening near their estuaries. Wave action, tides, and a strong longshore drift produce sand bars along the shore that divide lagoons from the sea and form across the mouths of rivers. The drift is towards the northwest from October to December and towards the southeast for much of the rest of the year. Several large wetlands, lakes, and lagoon complexes occur along the coast (see Rivers and Wetlands section).

Rolling Hills—The belt of Rolling Hills, lying at about 200-330 m elevation (average about 92 m), is parallel to the Coastal Plain and has numerous hills (e.g., Bomi Hills, Mount Barclay, Mount Gibi), valleys, and waterways. Rivers flow rapidly in this region over bedrock bottoms and have numerous rapids within their channels. In Grand Cape Mount County and the eastern part of the country this zone is forested. Most private agricultural concessions are located in the Belt of Rolling Hills. Here, agriculture and forestry are favored by prevailing topographical and climatic conditions.

Mountain Ranges and Plateaus—The Mountain Ranges and Plateaus lie behind the belt of Rolling Hills. Nearly half of the interior of Liberia lies between 200-330 m in elevation in this region. Major mountain ranges, consisting of long ridges aligned along a southwest-northeast axis, are the Mano River Mountain, Gibi Range, and Putu Range, whose summits reach 700 m. Summits in the Bong range reach 500 m in elevation. Other ranges include the Bea and Tienpo. The greatest width of this zone is about 128 km between the Lofa and St. Paul rivers in the northeast.

Northern Highlands—Two disjunct areas form the Northern Highlands. The Wologizi Range is in northeastern Lofa County, which is variously reported as reaching 1335-1380 m in elevation at Mt. Wutivi, which is reportedly the highest point in Liberia (UNDP 2006). The other highland area is the Nimba Mountain range, in northeastern Nimba County, which reportedly reaches maximum heights of 1,305 or 1,385 m on the Liberian side of the border (Gatter 1997; EPA 2007); the range is shared by Cote d'Ivoire, Guinea, and Liberia. Both the Wologizi and Nimba mountain ranges were once covered with forest and both contain rich iron ore deposits.

Soils

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^{o} and 28^{o}C with a growing period of more than 270 days. Dominant soils are Ferralsols and Acrisols (FAO classification; these are respectively, Oxisols and Ultisols 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). Large areas of Liberia (75% of the country) are Ferralsols (Deckers 1993) that are highly weathered soils with low fertility and low capacity to retain nutrients (low CEC, cation exchange capacity). They are suitable for surface farming techniques (traditional agriculture) and provide valuable materials for road construction. They are well-drained with good physical structure; their deep rooting depth makes up for their relatively low water-holding capacity (Van Wambeke 1974). Acrisols are less weathered than Ferralsols but still low in mineral nutrient reserves. The presence of a subsurface layer of clay accumulation may impede internal drainage and makes them more susceptible to erosion (Bationo et al. 2006).

Land Cover/Vegetation Zones

Liberia is situated within the Upper Guinean Forest that extends from Guinea at the northwestern extreme to the eastern limit in Cameroon. 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 1).

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 agricultural and forest area	1,317,873	13.7%
Agricultural 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	100.0%

Table 1 Land cover condition (from Bayol and Chevalier 2002)

There are three general types of forest, the evergreen or mixed evergreen/semi deciduous moist forests of western Liberia where there is a distinct dry season (under 100 mm rain/month), and the wet evergreen forests of eastern Liberia where the dry season is very short or absent. The highest hills in Liberia support the third forest type, submontane (or montane) forest above about 800-1000 m, although this zone is poorly-differentiated from the contiguous lowland forests. An extensive zone of degraded forest occurs near the coast and extends inland in central Liberia, separating the moist and wet forest blocks. The coastal zone is heavily impacted by settlements and agriculture, with a mosaic of sandy and rocky shores, mangroves and fresh-water swamps, grass/shrub savannas on sand, and coastal forests. Figure 2 depicts Liberia‘s forest and land cover based on 2003 satellite imagery.

River and Wetland Systems

Data on water resources in Liberia is limited. Prior to the conflict, the Liberian 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. During the crisis, these stations were abandoned and damaged during the crisis, and they have not been reestablished. Currently, the only data available for the flow of major watersheds is that acquired prior to 1990 (DAI 2008; A. D. Kpadeh, Liberian Hydrological Service, personal communication 2010), but most of that is not in digital format.

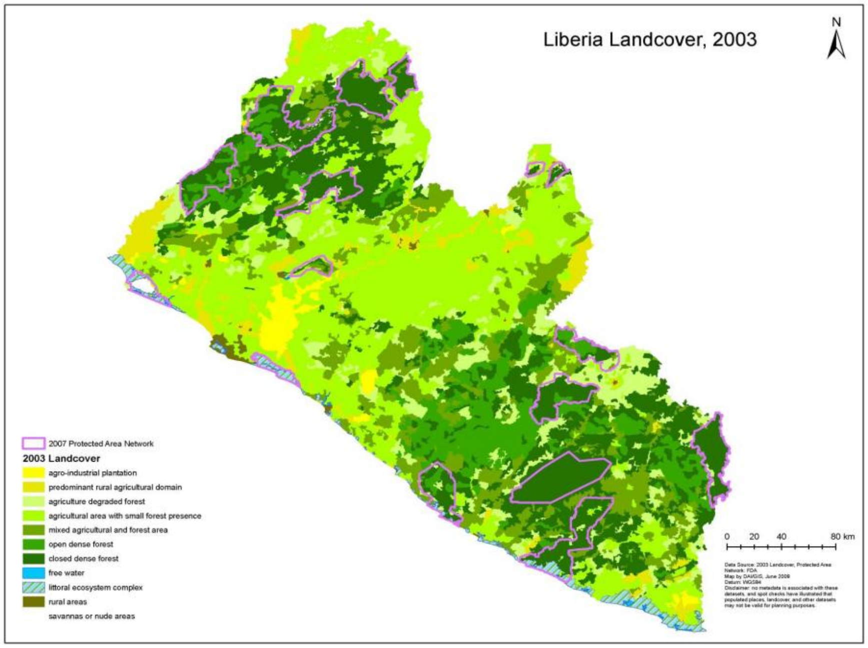


Figure 2 Land cover in 2003, interpreted from satellite remote sensing.

A limited amount of georeferenced mean monthly stream discharge data are available for internet download (IWMI 2010) 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).

Rivers—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 km^2), Lofa (or Loffa) (9,194 km^2), St. Paul (12,820 km^2), St. John (14,762 km^2), Cestos (or Cess) (10,000 km^2), and Cavalla (13,726 km^2) 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). Many smaller streams occur, however, including but not limited to the Junk, Farmington, Po, Du, Timbo, Sehnkwelm, Sino, Dugbe, Dubo, and Grand Cess rivers and in total Liberia has 16 main river basins (Figure 1).

The drainage system of Liberia conforms in large part to its geological structure and relief. Hence, most rivers flow northeast to southwest following the orientation of mountain ranges. Exceptions are found in the upper reaches of the Cavalla and Duobe (or Dube) rivers in southeastern Liberia. These rivers flow southeasterly apparently following fault lines before turning south.

As might be expected, extremes in flow in the rivers mirror seasonal peaks and troughs in rainfall associated with the West African Monsoons. As illustrated by the Upper St. Johns River near Baila (Figure 3). The hydrograph peaks in September and October with a long, relatively steep descending limb occurring from November to May. Flows then increase consistently from March to September with the steepest increase in discharge occurring from July to September.

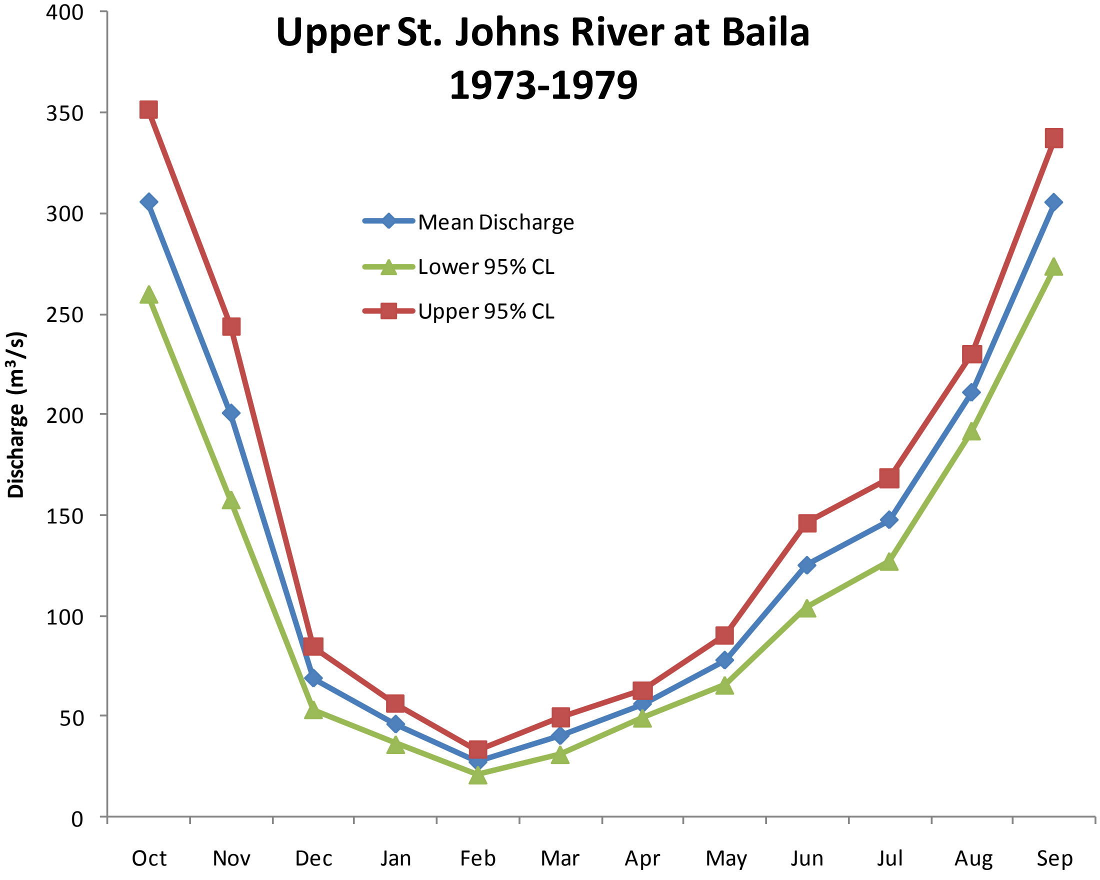


Figure 3 Hydrograph for the Upper St. Johns River at Baila, 1973-1979.

In their upper reaches most rivers in the country strongly erode their v-shaped valleys, but in lower, downstream reaches channels accumulate sand and gravel. Hence, the rivers may have extensively braided channels with small to large islands, some forested some not (e.g., St. Paul River, St. Johns River). During the rainy season, small sand banks shift almost daily, especially during large rainstorms when waters rise rapidly. These shifting sands, many rapids, the large change in water level between wet and dry seasons, the waterfalls, rocks and crags, make navigation on the rivers extremely difficult, so that even canoes are scarce except near the mouths of certain rivers. Likewise in the dry season (November-April) large areas of granite and gneiss, as well as sandbanks, are exposed. Near the coast some rivers (e.g., Po, Du, Bo, Junk) flow parallel to the coast for many kilometers before entering the sea. In this area, these rivers are sluggish, and because of gentle gradients and strong tidal currents, they cannot breach sand bars deposited in their estuaries by the heavy surf and longshore drift (Gatter 1997).

Wetlands—Near the coast many kilometers of tidal riverbanks (3,092 km), rivulets (645 km), and smaller tributaries (>1,000 km) are (or were) covered with mangroves that can reach 30 m in height. An estimated 600,000 ha of freshwater wetlands (swamps) occur in Liberia with only about 3% (20,000 ha) under cultivation (DAI 2008). Little is known about the specific values of freshwater wetlands in Liberia, from 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.

Lake Piso, the largest lake in Liberia (about 22 x 12 km), is a 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 lake and surrounding wetlands encompass an estimated 76,091 ha (Ramsar 2010). The area receives about 3,000-3,500 mm of rainfall a year, near maximal for Liberia. The wetland area contains five vegetation types: tropical evergreen rain forest, mangrove swamp forest, freshwater swamp forest, coastal savannah grassland, and coastal savannah woodland. Coastal sand covers most of the area (≤8-10 km from the seacoast inland). Beyond this range, sandy clay, clayish loam, and sandy loam soils occur. Highland forest occurs on Cape Mount Mountain which overlooks Lake Piso (Ramsar 2010). Lake Piso and its surrounding wetlands are designated a wetland of international importance (Ramsar 2010) and also are a proposed Important Bird Area (IBA) in Liberia identified by the Society for the Conservation of Nature Liberia and BirdLife International because it supports a significant assemblage of biome-restricted (Guinea-Congo forest biome) bird species (Fishpool and Evans 2001). The wetland and surrounding savannah and forest also supports migrating birds, sea turtles, reptiles, mammals (e.g., West African manatees, primates), and fisheries.

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). These wetlands are situated in the wettest area of Liberia, annually receiving over 4,500 mm of rainfall. The Marshall Wetlands supports large stands of mangroves, abundant bird life and diversity, abundant fish in the rivers and coastal waters, and aquatic dependent vertebrates such as imperiled crocodiles and manatees. The adjacent bio-medical research laboratory of the Liberia Institute of Biomedical Research is re-introducing chimpanzees used in research to islands in the wetland forests. The laboratory is anticipating the construction of an environmental research center that will serve as a center for environmental studies and research (EPA 2007; 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 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).
In the far southwest is Lake Shepherd (about 7,284 ha), Maryland County, a mixed salt, brackish, and fresh water system (Wiles 2005; EPA 2007). The lake is actually 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).

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). Beach sediment deposits are mainly unconsolidated white quartz that forms a veneer in the savannahs near the coast. Lagoon sediment deposits include silt, sand, and clay. These deposits are tidally derived from the sea and become trapped in the mangroves stands. The Bafu Bay Wetland is one of the few places along the coast adjacent to the evergreen forest in Liberia. Fishing is a major activity in the area.

The Gbedin Wetlands (about 4,532 ha, St. Johns River drainage), another wetland considered of international importance (Ramsar 2010), are 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 man-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 imperiled vertebrates (EPA 2007; Ramsar 2010).

SOCIAL SETTING

Political Jurisdictions

Liberia is divided into a hierarchical arrangement of political jurisdictions consisting of 15 counties (each with a designated county seat), 136 districts arrayed within counties, and numerous clans arrayed within districts. Individual counties comprise from 4-18 districts and varying numbers of clans. The six largest counties (>7,770 km^2) are: Nimba County--11,551 km^2; Lofa County-- 9,982 km^2; Gbarpolu County--9,953 km^2; Sinoe County-- 9,764 km^2; Bong County--8,754.0 km^2 ; and Grand Bassa County--7,813.7 km^2. Other counties range in area from 1,880 km^2 (Montserrado County) to 5,663 km^2 (Rivercess County) (LISGIS 2010).

Population Characteristics

The estimated population of Liberia is 3.440 million people (36 individuals/km^2), a 65% increase since 1984 (LISGIS 2010). Liberia's population growth rate[1] in 2008 was estimated to be 5.3% and is expected to decline to 2.1% by 2025 (Table 2). Net migration is positive as a result of in-migration from surrounding countries that have also experienced political unrest. The major coastal cities, which also include major population centers are: Monrovia, the capital and largest city in the country (Greater Monrovia District, population 970,824; LISGIS 2010); Robertsport; Buchanan; Greenville; and Harper. An estimated 58% of the population of Liberia lives along the coast (EPA 2007). The highest concentration of population occurs in and around coastally located Monrovia, the capital and largest city in the country, including Montserrado and nearby counties (LISGIS 2010). Montserrado County has 595 individuals/km^2, and nearby Margibi County has 78 individuals/ km^2, Bomi County, 44 individuals/ km^2, Bong County, 38 individuals/ km^2, and Grand Bassa County, 28 individuals/ km^2, which includes the seaport Buchanan. Other counties with moderate to high relative densities include Maryland County (59 individuals/ km^2) which includes the coastal city of Harper in the extreme southeast, bordering Côte d'Ivoire; northcentral Nimba County (40 individuals/km^2), bordering Guinea and Côte d'Ivoire; Lofa County (72 individuals/km^2) in the west, bordering Sierra Leone; and Grand Cape Mount County (27 individuals/km^2) in the northwest, which includes the coastal city of Robertsport and borders Sierra Leone and Guinea. The remaining 6 counties have densities ≤15 individuals/km^2 (Figure 4). Half of Liberia's population lives in and around Monrovia.

Life expectancy has increased substantially since the mid-1990s and infant and childhood mortality has declined as well (Table 2).

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[1] Growth rate is the average annual percent change in the population, resulting from a surplus (or deficit) of births over deaths and the balance of migrants entering and leaving a country. The rate may be positive or negative. Also known as population growth rate or average annual rate of growth.

This is reflected in the age structure (Figure 5) which also shows that essentially equal gender distribution of the population. One result is that over 40% of the population is "dependent," defined as under 5 and over 65 years old. On average, household size is 5.6 persons, with the proportion of female-headed households varying from 5%

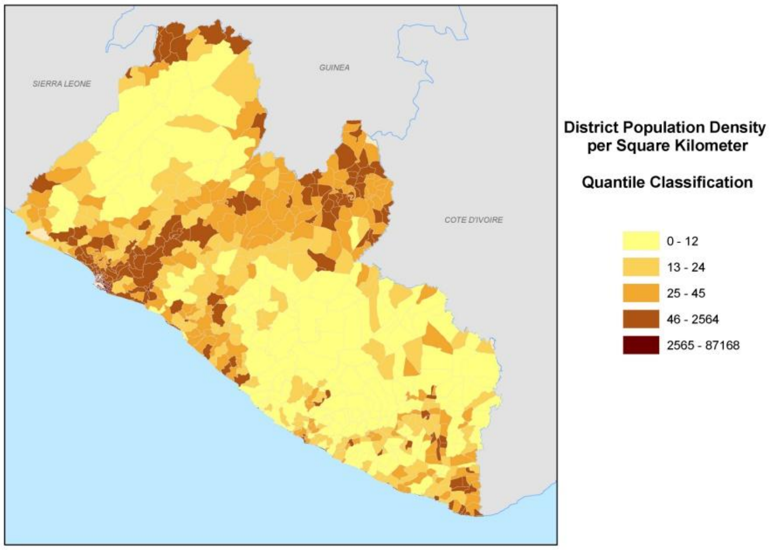

Figure 4 District popuation density, individuals/km^2.

Demographic Indicators

	2008	1995	2005	2015	2025
Population					
Midyear population (in thousands)	3,440	1,900	2,930	4,196	5,284
Growth rate (percent)	5.3	4.0	6.3	2.5	2.1
Fertility					
Total fertility rate (births per woman)	5.4	6.2	5.5	4.7	3.8
Crude birth rate (per 1,000 population)	39	45	42	34	29
Births (in thousands)	135	86	122	144	156
Mortality					
Life expectancy at birth (years)	56	28	54	59	62
Infant mortality rate (per 1,000 births)	80	230	85	68	52
Under 5 mortality rate (per 1,000 births)	120	357	130	100	74
Crude death rate (per 1,000 population)	11	34	12	10	8
Deaths (in thousands)	39	64	36	41	43
Migration					
Net migration rate (per 1,000 population)	25	28	34	0	0
Net number of migrants (in thousands)	87	53	99	0	0

Table 2 Demographic characteristics of the Liberian population (Source: US Census Bureau, International Database)

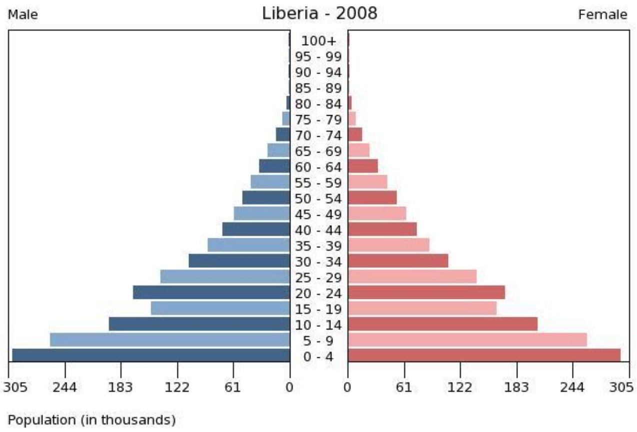

Figure 5 Age structure of the Liberian population (Source: US Census Bureau, International Database)

in Bomi County to 21% in Lofa County, the area most heavily and continually affected by violence during the conflict (MPEA 2008). The effects of the conflict are evident as well in the spatial distribution of disabled people as a percentage of the population.

Some uncertainty still remains in the aggregate population at the county level because of the displacement that occurred during war years (CFSNS 2006). Many people were displaced at least twice during the war; although many have returned, in some areas more than 10% of the population has not been re-settled (Figure 6). Their reasons for leaving, and for returning, are varied as is acceptance of them by the settled community. In some cases, returnees found others had replaced them on the land.

Life expectancy has increased substantially since the mid-1990s and infant and childhood mortality has declined as well (Table 2). This is reflected in the age structure (Figure 5) which also shows that essentially equal gender distribution of the population. One result is that over 40% of the population is “dependent,” defined as under 5 and over 65 years old (Figure 7). On average, household size is 5.6 persons, with the proportion of female-headed households varying from 5% in Bomi County to 21% in Lofa County, the area most heavily and continually affected by violence during the conflict (MPEA 2008). The effects of the conflict are evident as well in the spatial distribution of disabled people as a percentage of the population (Figure 8).

In Liberia most rural households are food insecure, meaning that they lack access at all times of the year to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Nationally, 80% of the rural population was either moderately vulnerable (41%) or highly vulnerable (40%) to food insecurity (GoL 2007). Different rural livelihood profiles provide differing degrees of food security; the most food insecure groups were those involved in palm oil production and selling followed by hunters and contract laborers.

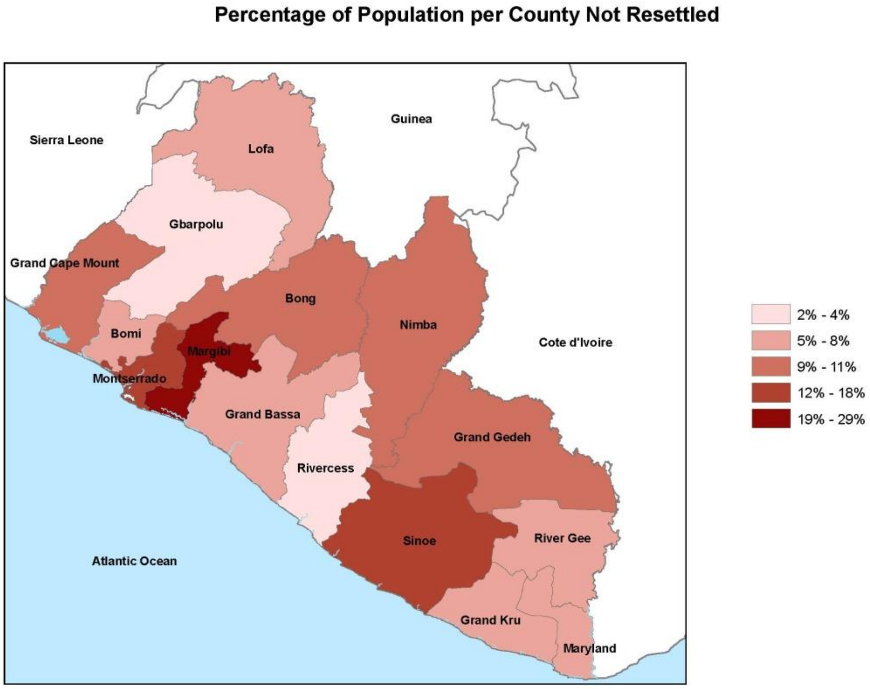

Figure 6 Percentage of population per county not resettled.

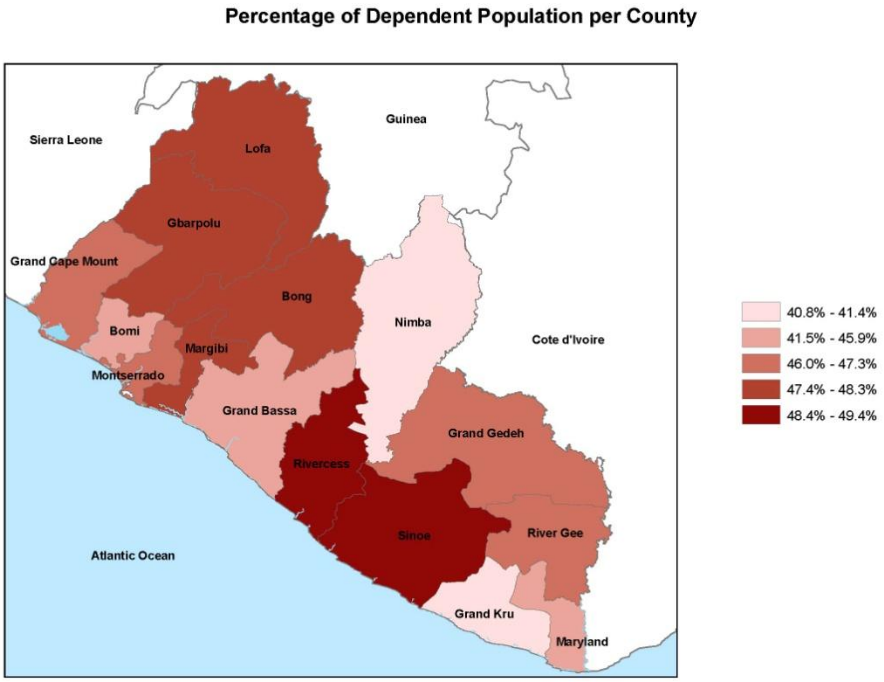

Figure 7 Percentage of dependent population per county.

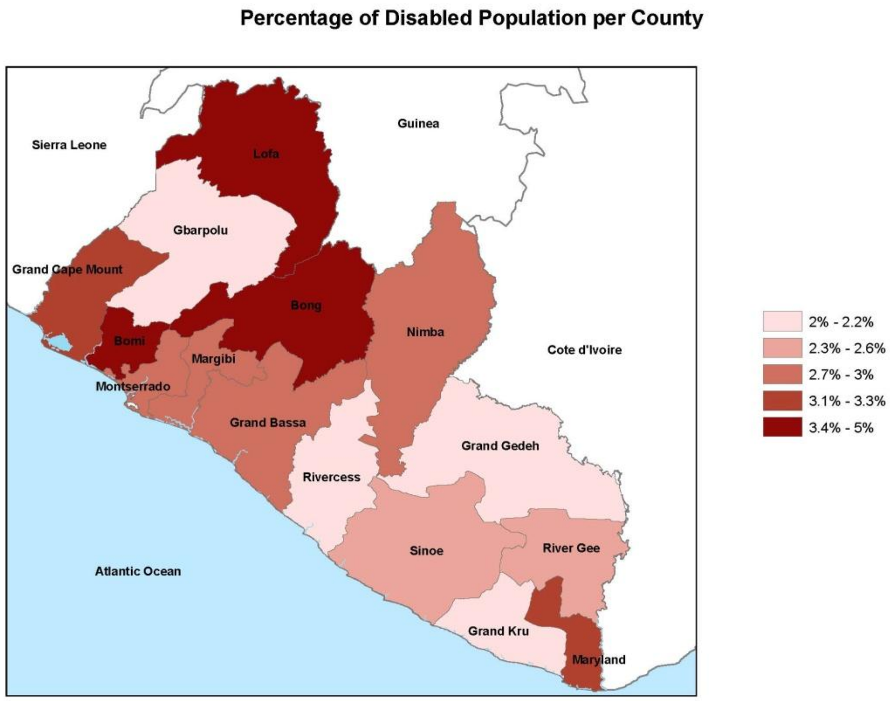

Figure 8 Percentage of disabled population per county.

CLIMATE

GENERAL

The climate of West Africa 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. The most documented cause of these variations on an inter-annual timescale is the El Niño Southern Oscillation (ENSO). The West African Monsoon 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).

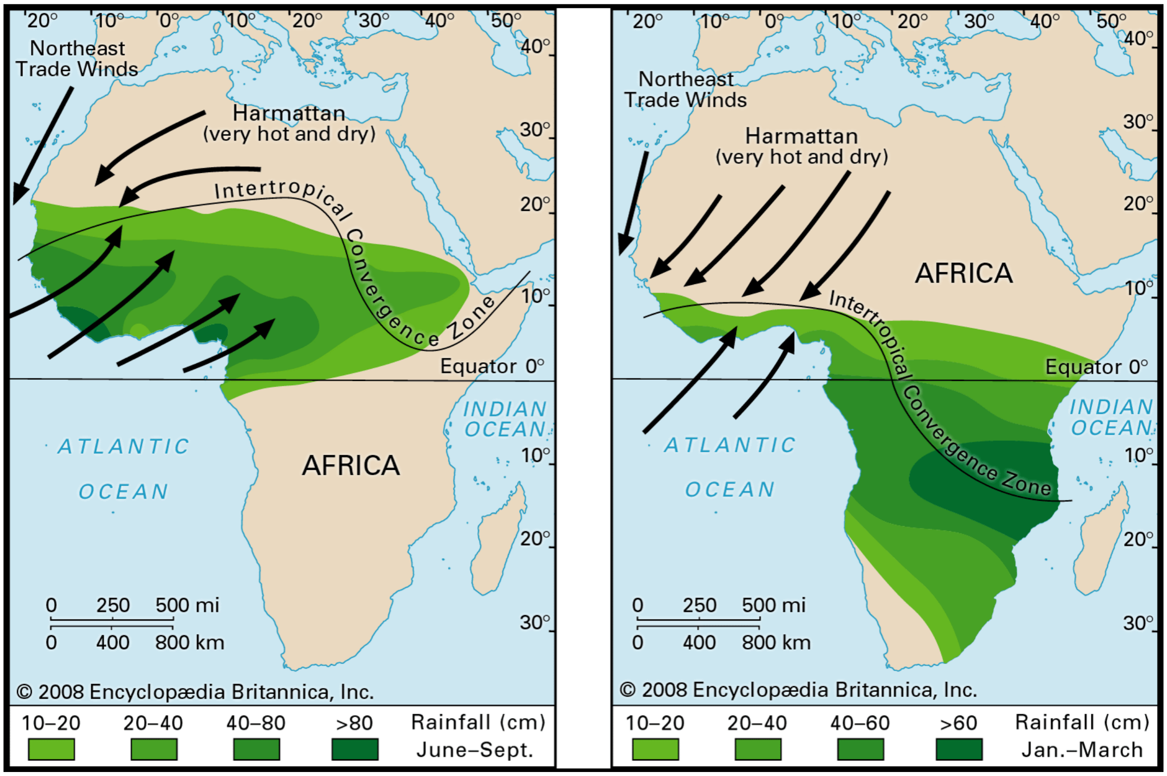

Figure 9 West African monsoon (Encyclopedia Britannica Online Accessed 19 April 2011)

The Inter-Tropical Convergence Zone is a latitudinal band of convective activity that is a critical link in the Earth's global circulation pattern that redistributes solar energy from the tropics toward the poles. The ITCZ, also known as the Equatorial Convergence Zone or Inter-Tropical Front, is characterized as a region of calm winds separating the northeasterly and southeasterly trade winds (known to sailors as the doldrums). The location of the ITCZ oscillates on an annual basis, reaching its northern most extent during the northern hemisphere summer and its southern most extent during the northern hemisphere winter. 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 in land temperatures. In Africa, the northern extent of the ITCZ is just south of the Sahel at about 10-15° N. During the winter, the ITCZ's southern progression is limited by the West African Monsoon (Figure 9).

The West African Monsoon is a wind pattern driven by differential heating of land and sea. The wind pattern shifts from predominantly southwesterly during the summer to northeasterly during the winter. During summer the southwesterly 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 northeasterly flow, referred to as the Harmattan Wind, is characterized as extremely dry and dust laden.

LIBERIA—CURRENT CLIMATE

Liberia is located in West Africa along the Atlantic coast between the latitudes of 4-8°N. This location allows Liberia's climate to be described in terms of two separate climate regimes. The equatorial climate regime, where rainfall occurs throughout the year, is restricted to the southernmost part of Liberia. The second is a tropical regime dominated by the interaction of the ITCZ and the West African Monsoon. Liberia's coastal location allows the southwesterly flow of the monsoon to prevail most of the year, maintaining a thin layer of moist marine air near the surface, although the Harmattan Wind typically intrudes for brief periods during the winter in coastal areas (duration typically less than two weeks). This interaction of the ITCZ with the monsoon flow produces the characteristic summer wet season/winter dry season of a tropical climate.

The moisture-laden West African Monsoon 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 is >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. 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 average for the coastal region. The high rainfall of the Nimba Mountain ranges is also due to its unique topography (Figure 1; Gatter 1997).

Temperature in Liberia is determined by its tropical location, where the sun is almost 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.

Temperatures in Liberia are strongly influenced by season. 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). For the period of 1970-1999, temperatures typically ranged from 24 to 25° C during the wet season and 24 to 27° C during the dry season (McSweeney et al. 2008). These temperature ranges are consistent with those reported by Coolidge (1930) of 24 to 26° C and 24 to 29° C during the wet and dry seasons respectively.

Relative humidity is generally high over all of Liberia owing to its coastal location. 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 average annual rainfall in the coastal belt is >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. The high rainfall of the Nimba Mountain ranges is also due to its unique topography (Gatter, 1997).

The annual pattern of rainfall in Liberia typically occurs as follows (Figure 10): in early May, the ITCZ reaches Liberia on its way north, and thunderstorms and strong winds mark the beginning of the rainy season; heavy rainfall occurs throughout June at which time the surface front is well inland; and by July or August rainfall decreases at which time the southern edge of the ITCZ is high overhead (Gatter, 1997). This period is called the middle dry season (or “middle dries”) even though the season is never literally dry and in some areas rainfall does not decrease. The middle dry season is most distinctive and marked in southeast Liberia, where two rainfall peaks occur. In the northern half of the country one prolonged wet season is the norm as the zone of limited rainfall marked by the southern boundary of the ITCZ, never reaches so far north, allowing heavy and sustained rainfall to persist from June to September (Gatter, 1997). This rainfall pattern repeats itself as the ITCZ moves southward during the northern winter and increased precipitation occurs again in August and September, which are the wettest months in some areas. The end of the rainy season is marked by thunderstorms associated with the surface front of the ITCZ (Gatter, 1997).

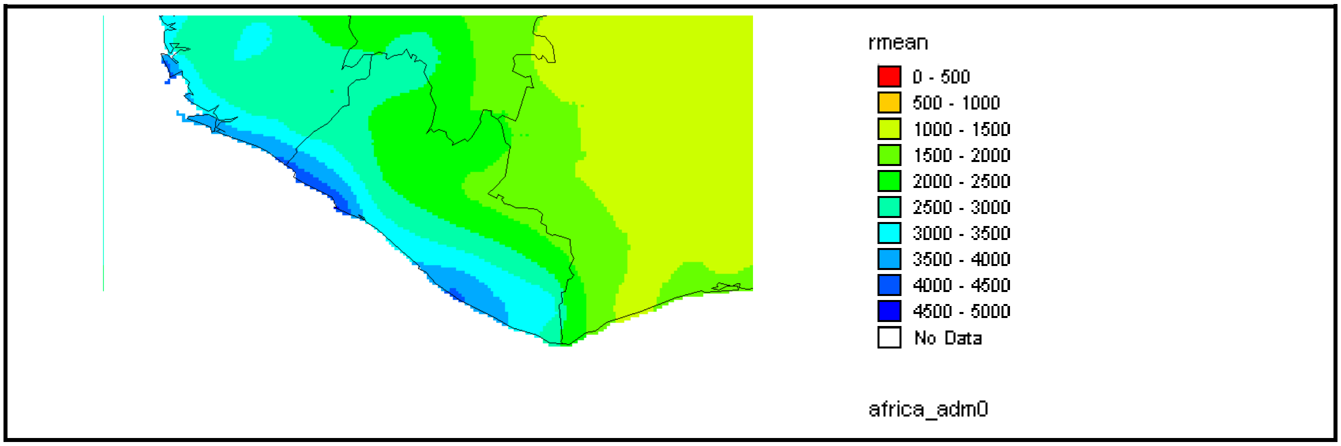

Figure 10 Annual average precipitation totals (mm) based on the period 1950-2000 (Source: WorldClim; modeled data).

For Liberia the primary sources of variability at inter-annual and decal time scales relate to variations in sea surface temperatures in either the tropical Atlantic or changes in the global sea surface temperature distribution (Rodríguez-Fonseca et al. 2011). In the case of warmer tropical Atlantic sea surface temperatures, the warmer water weakens the land-sea temperature contract that drives the southwesterly monsoonal flow; as a result, the monsoon flow does not penetrate as far inland, increasing rainfall closer to the coast while decreasing rainfall in the Sahel. Cooler Atlantic sea surface temperatures strengthen the West African Monsoon, driving the moist air mass further inland which increases rainfall in the Sahel at the expense of coastal areas.

It is difficult to determine whether there is a long-term trend in rainfall due to the high variability exhibited in the rainfall record. McSweeney et al. (2008) note that the observational record is punctuated with particularly wet (1960s and late 1970s) and dry (early 1970s and 1980s) periods. This variability is also noted today as 2005-2006 were noted as dry years while 2007-2009 were wet (Figure 11). Although McSweeney et al. (2008) state that rainfall has declined since the 1960s, current rainfall levels (annual average for the period 2004-2009 of approximately 4500 mm) is significantly higher than observed at the time of Coolidge (1930), 3900 mm.

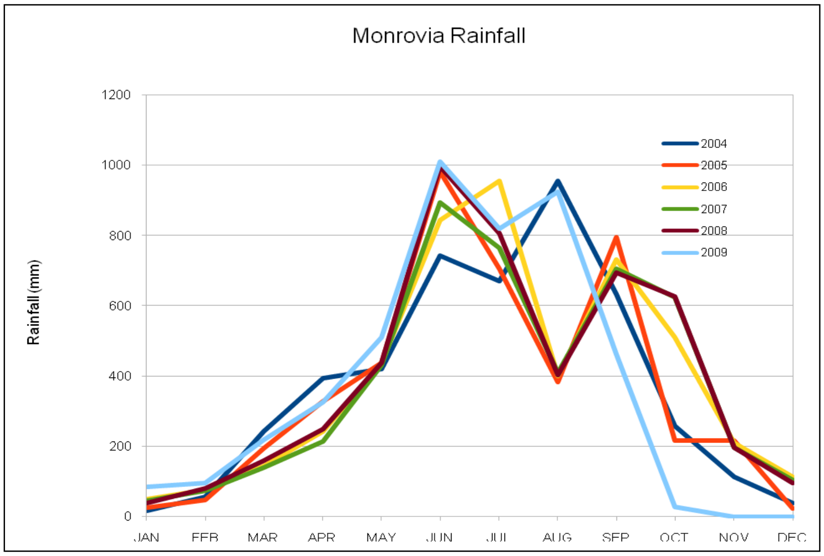

Figure 11 Monrovia rainfall, recorded 2004-2009 (Source: UNMIL).

Temperature trends are similarly difficult to discern from the observational record. From 1960 to 2006, mean annual temperature increased by 0.8° C (McSweeney et al. 2008). However, extending the time period back before 1930 (using data from Coolidge, 1930) reveals a slightly negative trend to date. Of note is the finding McSweeney et al. that the proportion of hot/cold nights has changed between 1960 and 2003. Hot/cold nights are defined by the hottest/coldest 10% of nights in the current climate. Hot nights now represent over 15% of the days each year rather than the expected 10%. Cold nights have declined from the defined 10% to less than 5%. While Coolidge (1930) does not provide adequate information to examine the proportion of hot/cold nights, a warm shift in the mean temperature for this period implies that it is likely that back in the early part of the 20th century the percentage of hot nights was greater and percentage of cold nights lower than currently observed.

LIBERIA—FUTURE CLIMATE

We approached climate modeling in four ways: ensemble projections for three representative areas (Monrovia, Nimba, and Sapo National Park), statistical down-scaling for the entire country, dynamic down-scaling for the entire country, and a constructed aridity index for examining the effects of climate change on social and natural systems. Notably, most GCMs have difficulty correctly reproducing a number of 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). For this reason we 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)[2] 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. We focus our examination on three areas: coastal (Monrovia), inland (Nimba), and southern (Sapo National Park).

In projecting future climatic conditions, assumptions must be made about how the human component of the climate system will evolve over the course of 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 IPCC developed four different families of scenarios. We focus on three of those families described in various IPCC documents (IPCC, 2007).

> 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.

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[2] 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.

We modeled temperature and precipitation for the three emission scenarios and report the ensemble averages for each scenario, as well as standard deviation, maximum and minimum values, and the means across the scenarios.

Ensemble Projections for Representative Areas

Expected 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 1-3). The most conservative estimates on temperature change (scenario B1) have 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 3 emission scenarios (Tables 3-5) 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 emission scenario the AOGCMs are quite consistent in predicting warmer conditions throughout Liberia.

The AOGCM predictions of precipitation in Liberia lack any sense of consistency. Forecast changes in precipitation in Monrovia range from 36% decreases to 21% increases in wet season rainfall. The overall ensemble prediction across emission scenarios gives a slight increase in wet

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 3 Potential change in temperature (^{o}C) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Monrovia.

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 4 Potential changes in temperature (^{o}C) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Nimba.

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% decreases 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.

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

Table 5 Potential change in temperature (^{o}C) and percent change in rainfall for the dry (Dec-Feb) and wet (Jun-Aug) seasons at Sapo National Park.

Statistical Downscaling

To provide a glimpse of the potential changes in the spatial pattern of precipitation, we used output from the National Center 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). We chose CCM3 because 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 down-scaling.

The spatial pattern of temperature change is illustrated by the mean high and low daily temperatures (Figure 12) that show that changes in high temperatures will be less than 2^oC throughout the country but average low temperatures (i.e., nighttime temperatures) will increase more than 2^oC in the interior. Comparing current with 2050 projections of average maximum temperature in February, generally the hottest month (Figure 13), shows a 1^o-2^o C increase throughout most of the country with the highest temperature approaching 36^o C in the interior. For the same month, the comparison of current to projected 2050 average low temperatures indicates a 2^{o} C increase in nighttime temperature along the coast in the west and the northeastern border area (Figure 14).

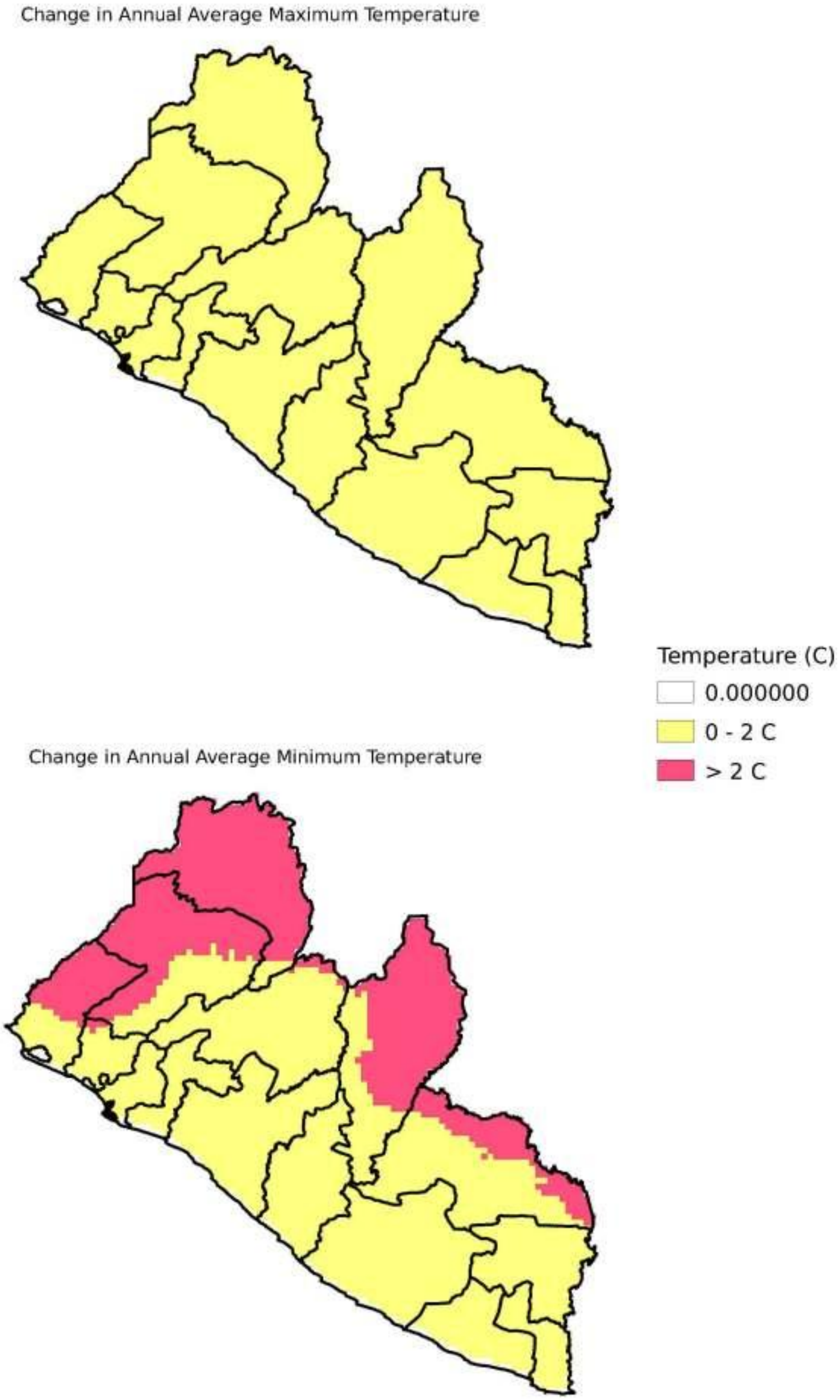
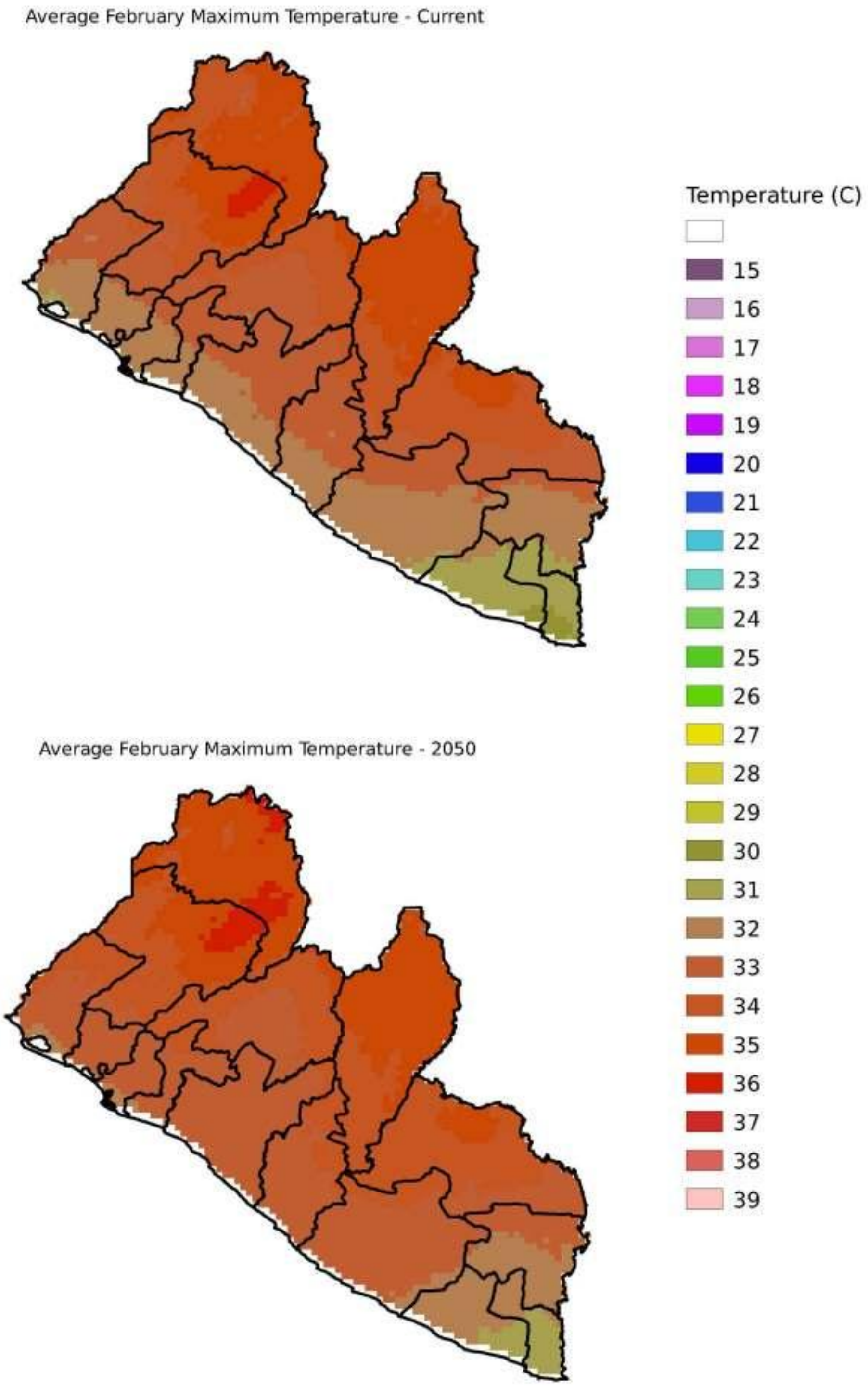


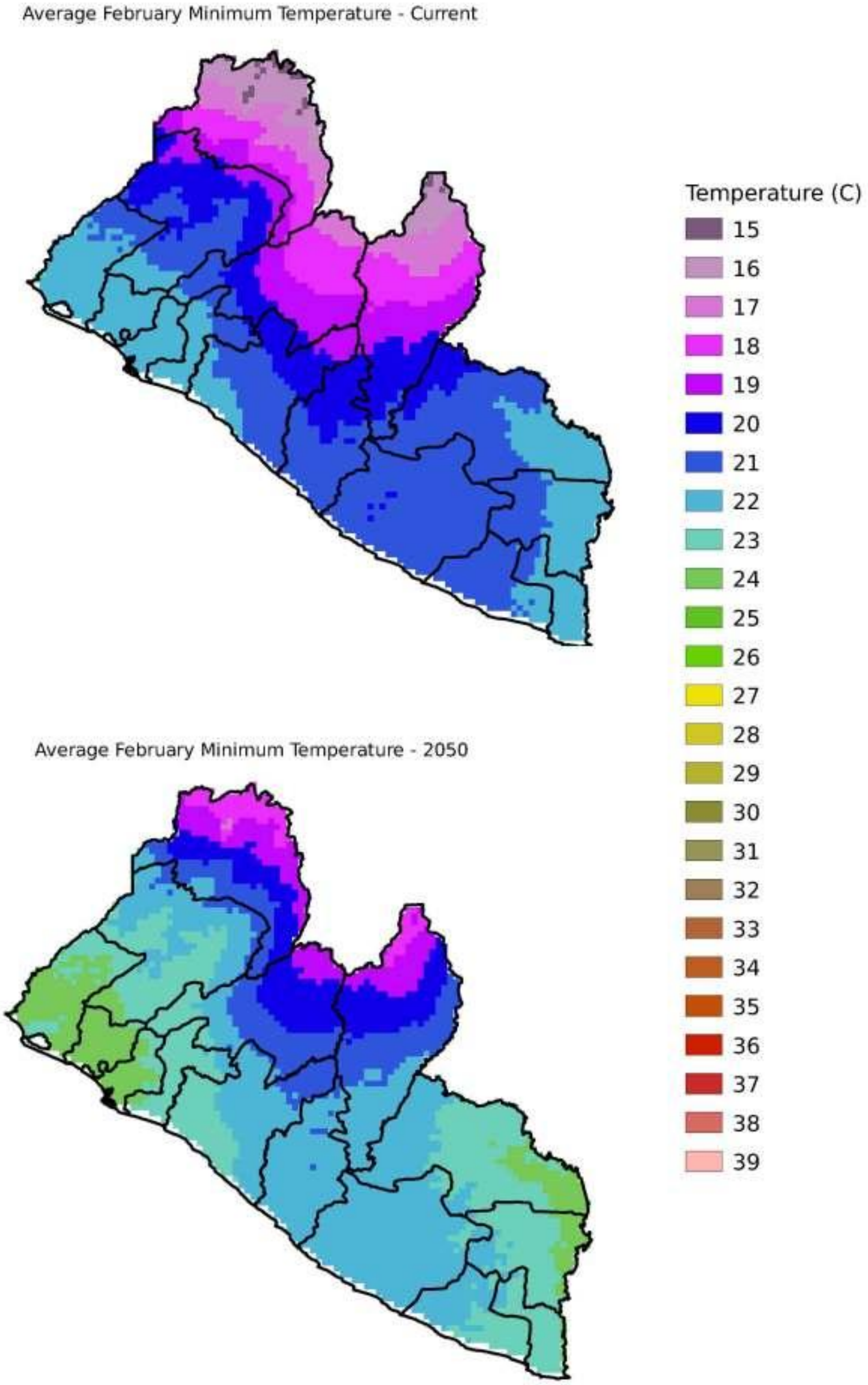
Figure 12 Change in average annual maximum and minimum temperatures, current vs. 2050.



Average February Maximum Temperature - Current

Average February Maximum Temperature - 2050

Figure 13 Average daily maximum temperature in February, current vs. 2050.



Average February Minimum Temperature - Current

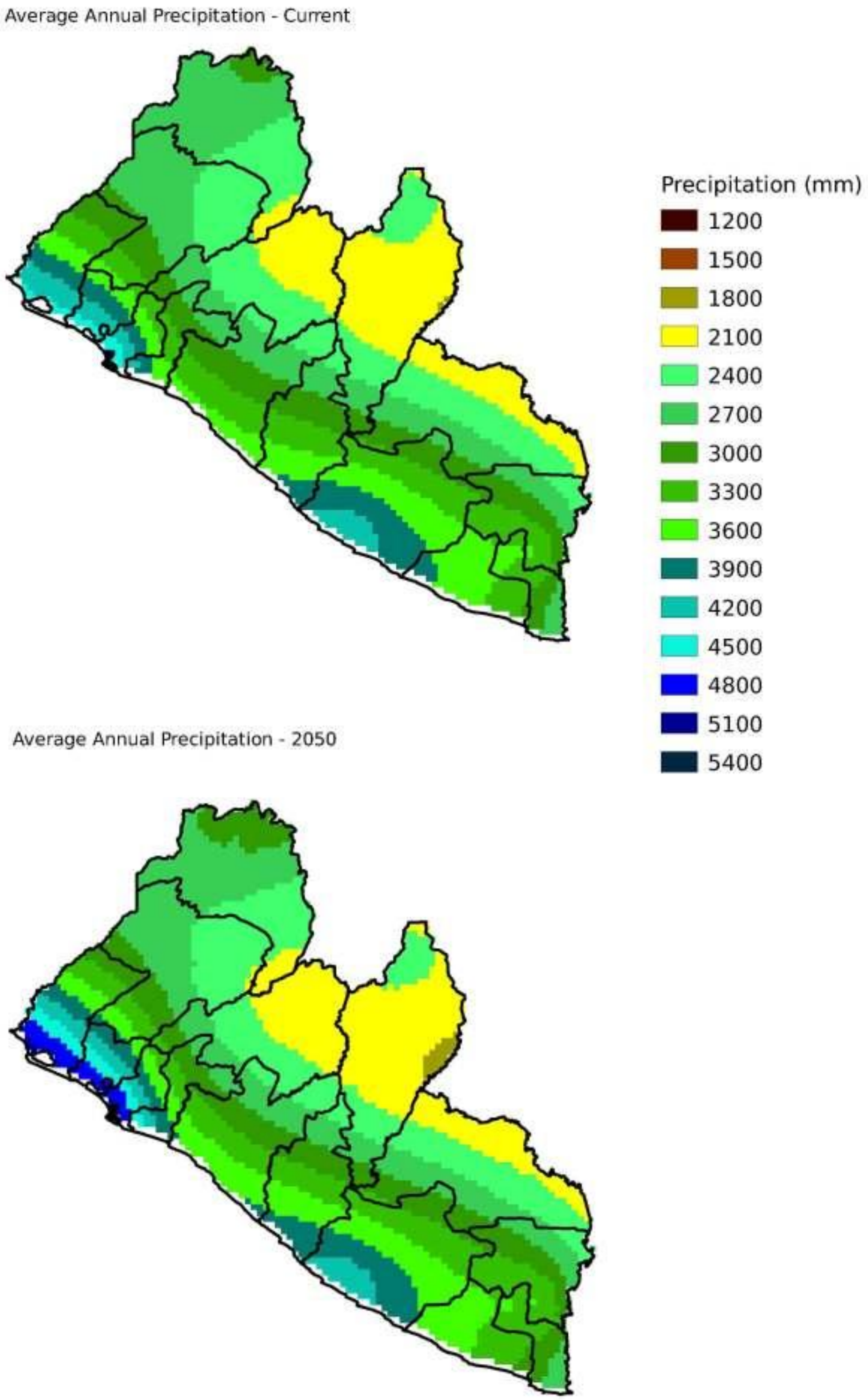
Average February Minimum Temperature - 2050

Figure 14 Average daily minimum temperature in Febrary, current vs. 2050.

The spatial pattern of average annual precipitation currently versus 2050 (Figure 15) 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. 16-19) 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 16). July brings the start of the mid-dry 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 northern part of 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 has a tendency to impose current patterns of spatial variability upon the 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.

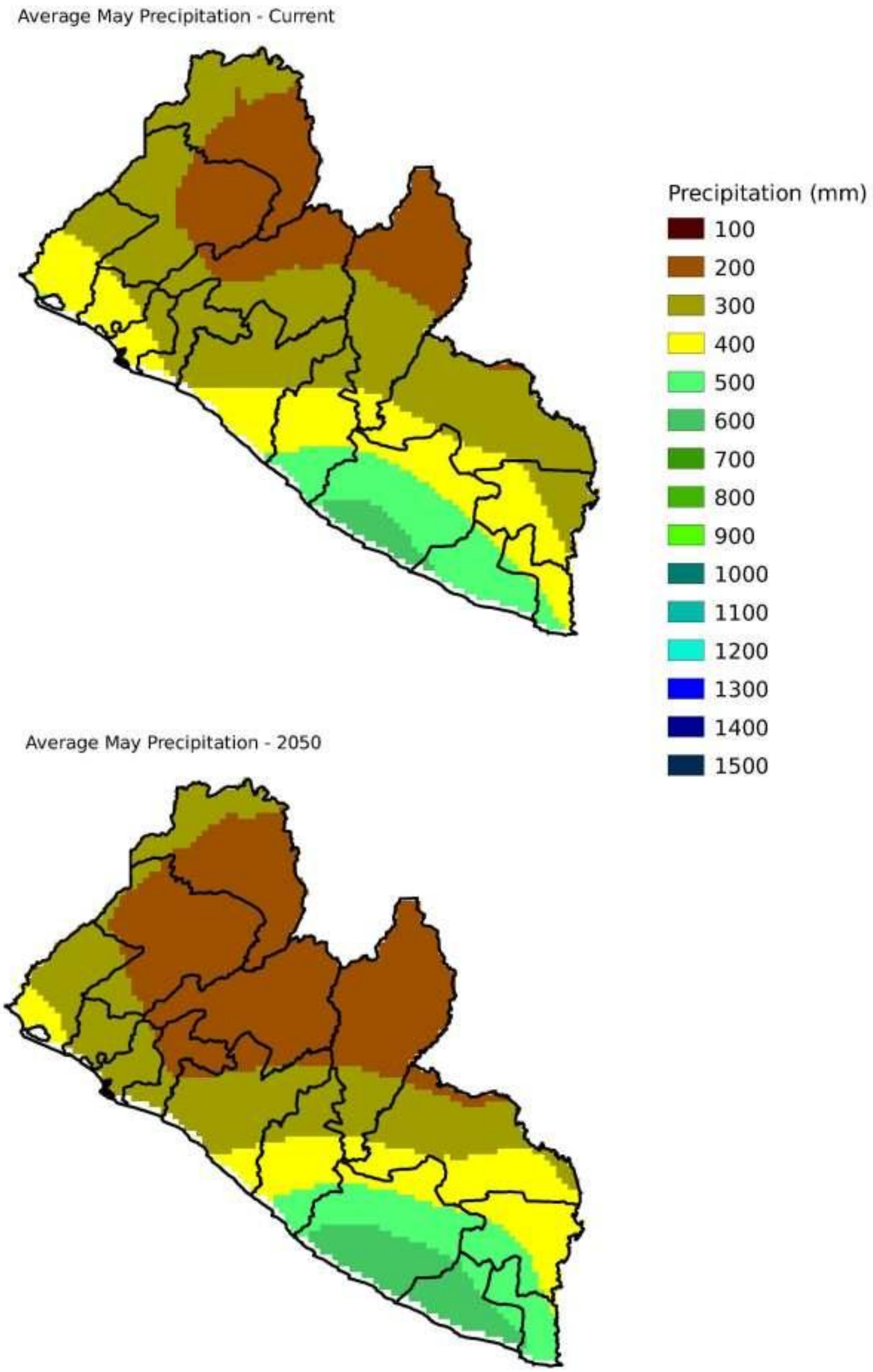
Because of the complexity of correctly reproducing a number of key features of the atmospheric circulation patterns over West Africa, projections of rainfall by climate models are mixed and uncertain. Our ensemble modeling projections of rainfall among three representative meteorological stations also 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 dynamics 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.



Average Annual Precipitation - Current

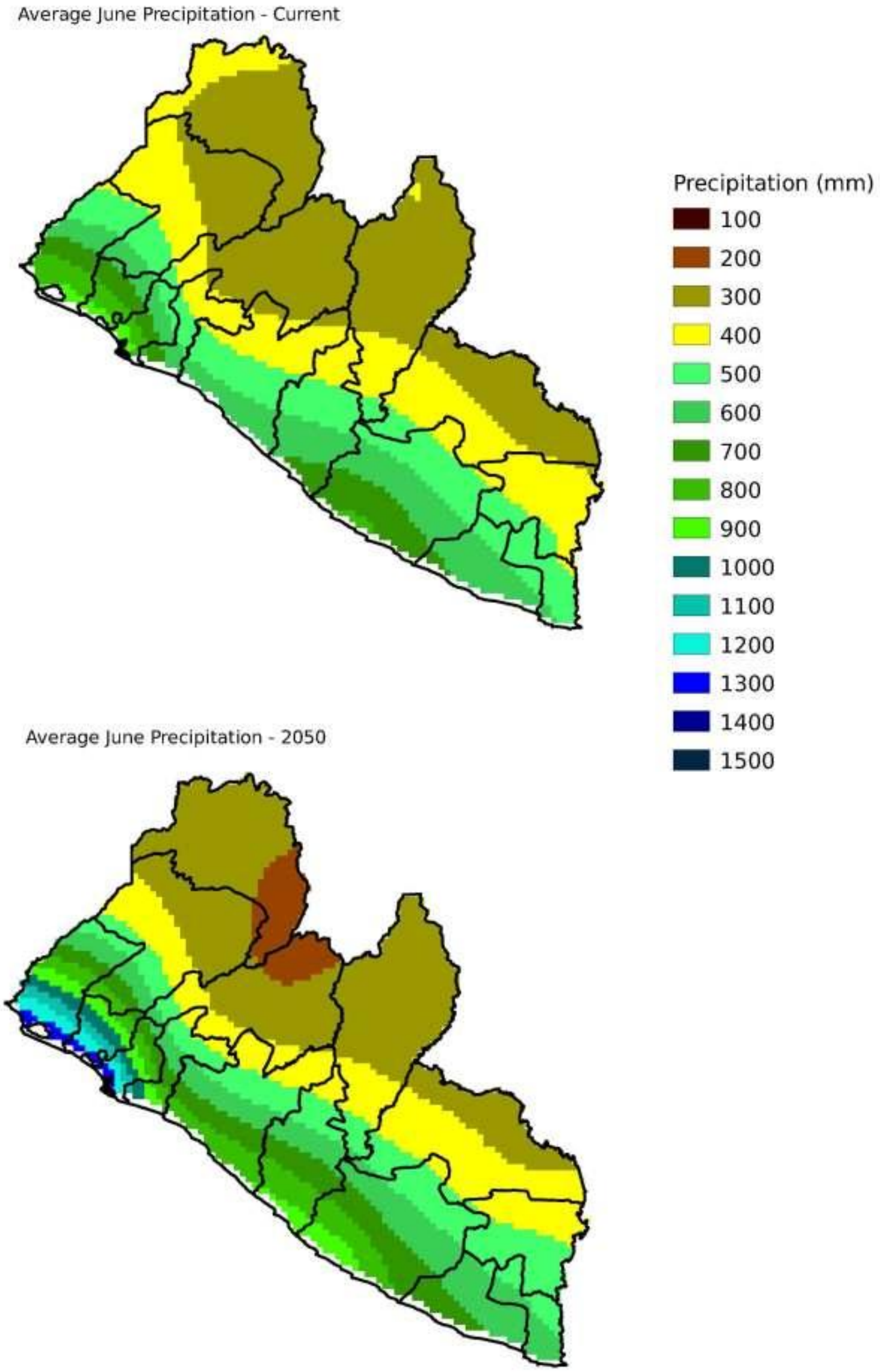
Average Annual Precipitation - 2050

Figure 15 Average annual precipitation, current vs. 2050.


Average May Precipitation - Current

Average May Precipitation - 2050

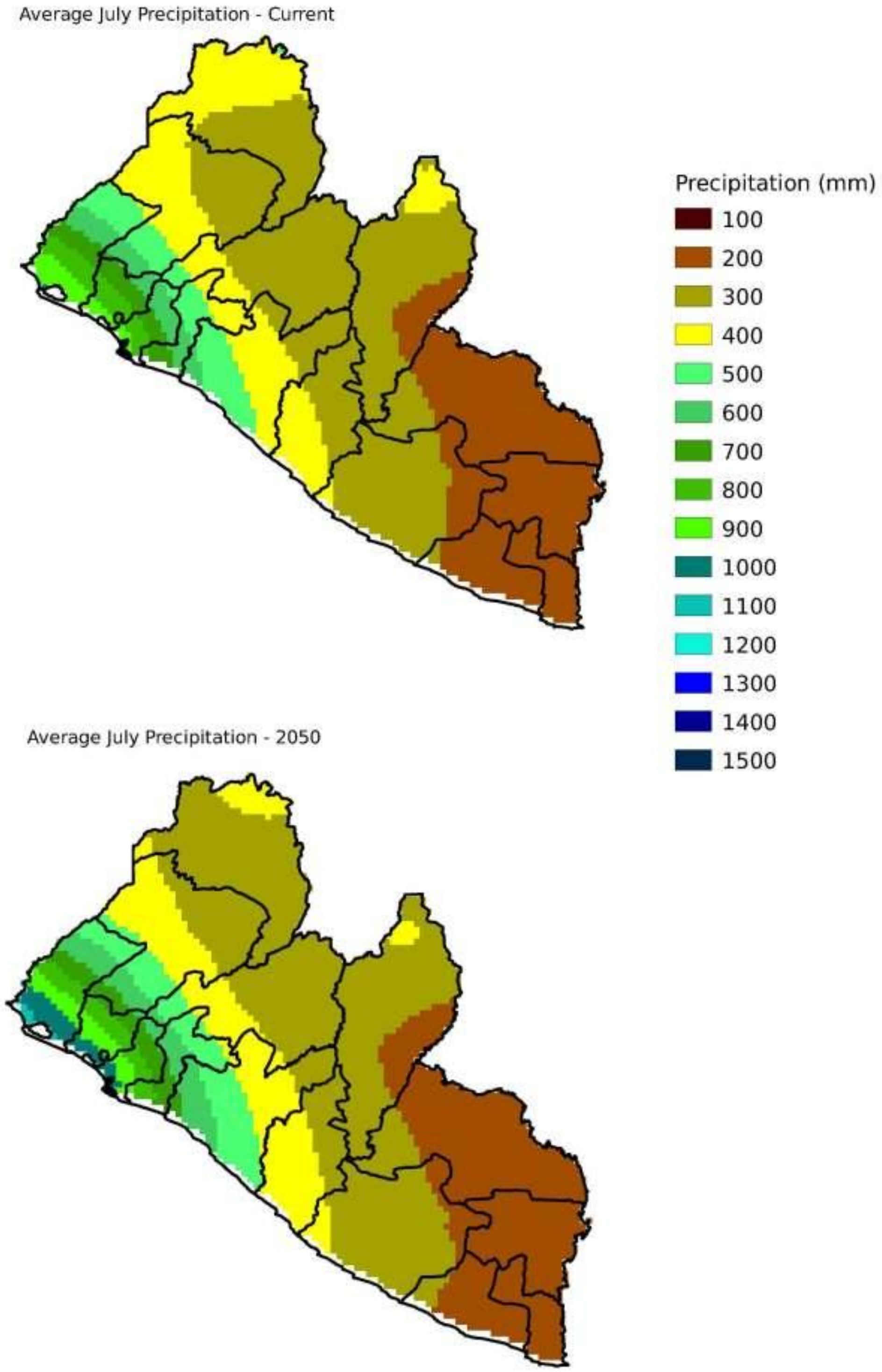
Figure 16 May (wet season) average monthly precipitation, current vs. 2050.



Average June Precipitation - Current

Average June Precipitation - 2050

Figure 17 June (wet season) average monthly precipitation, current vs. 2050.



Average July Precipitation - Current

Average July Precipitation - 2050

Figure 18 July (wet season) average monthly precipitation, current vs. 2050.

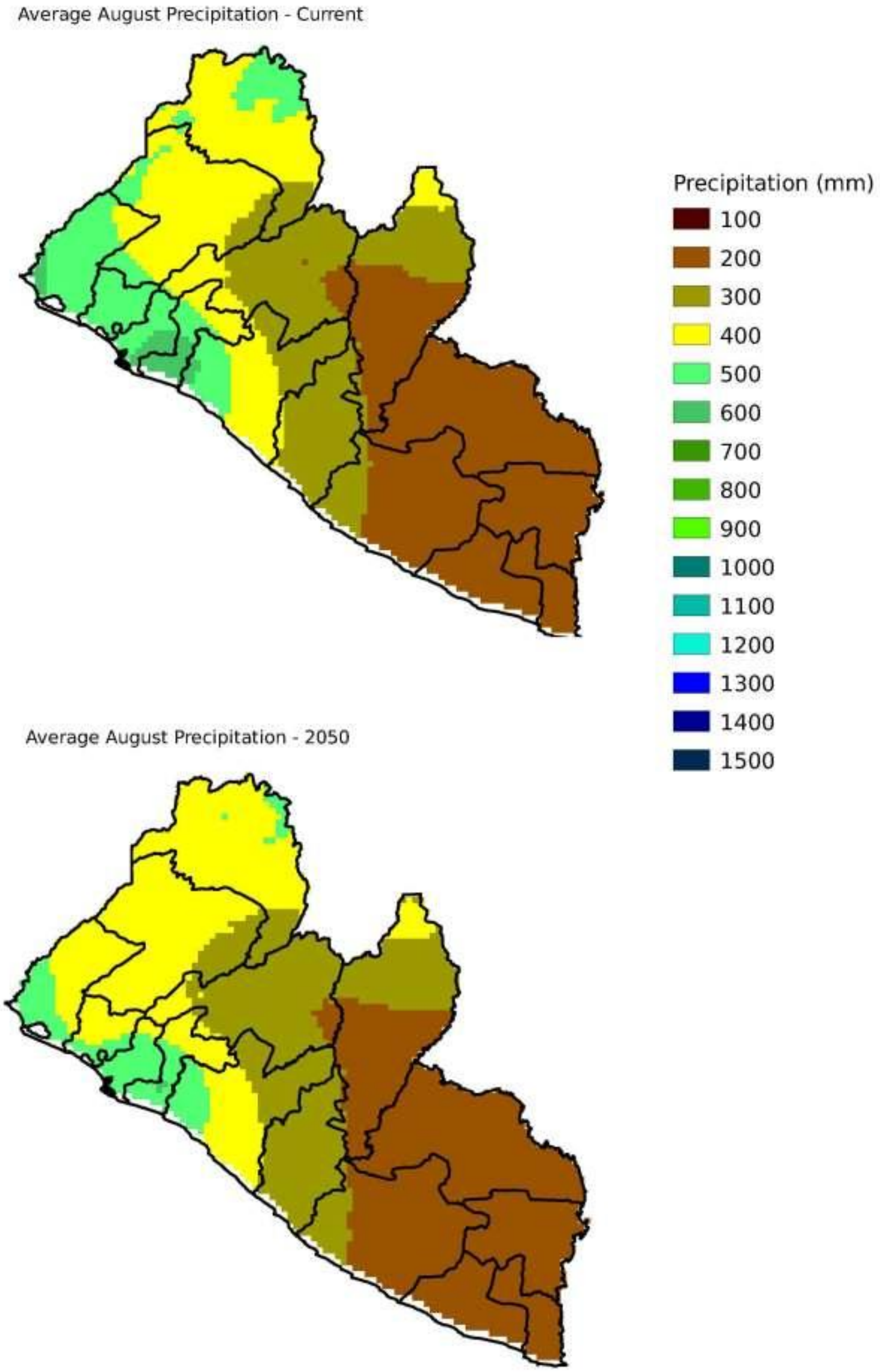


Figure 19 August (wet season) average monthly precipitation, current vs. 2050.

Dynamic Downscaling

Dynamic downscaling is the nesting of 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 goal of a regional climate model (RCM) is to provide a more detailed representation of the important atmospheric processes contributing to climate variations. It is important to note that one difficulty with RCMs is setting the myriad parameters available within the model that control convection and land-surface interactions. Variations in these parameters can result in significant differences in model results. This analysis did not include an exhaustive evaluation of the model's input parameter space due to the high computational requirements for such work. This is also why only one future emissions scenario was considered (A1B). Our focus in examining 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^o-2^o C increase throughout most of the country. Results from the dynamic downscaling indicate slightly stronger warming of just over 3^o C along a band paralleling the coast (Figure 20). Average minimum temperatures for February did not show any significant warming which is in sharp contrast to the 2^o C increase in nighttime temperature along the coast in the west and the northeastern border area found with the statistical downscaling (Figure 21). A 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.

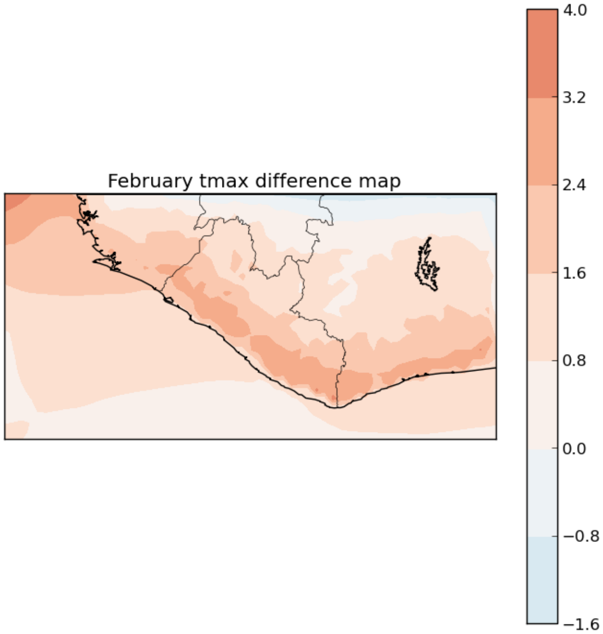


Figure 20 Change in February average maximum temperature for dynamic downscaling (^{o} C).

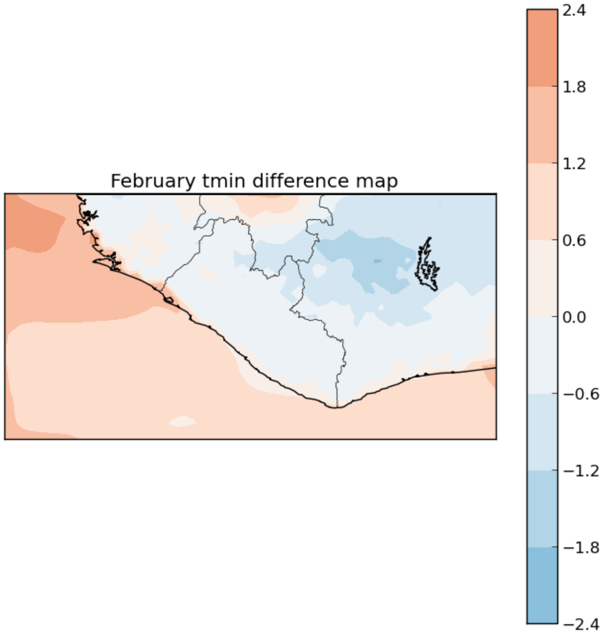


Figure 21 Change in February average minimum temperature for dynamic downscaling (^{o} C).

During the wet season (May to August) the statistical downscaling indicated increases rainfall focused along the coast with inland regions experiencing normal to slightly reduced rainfall. 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 22). The 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 14). July brings the start of the mid-dry period.

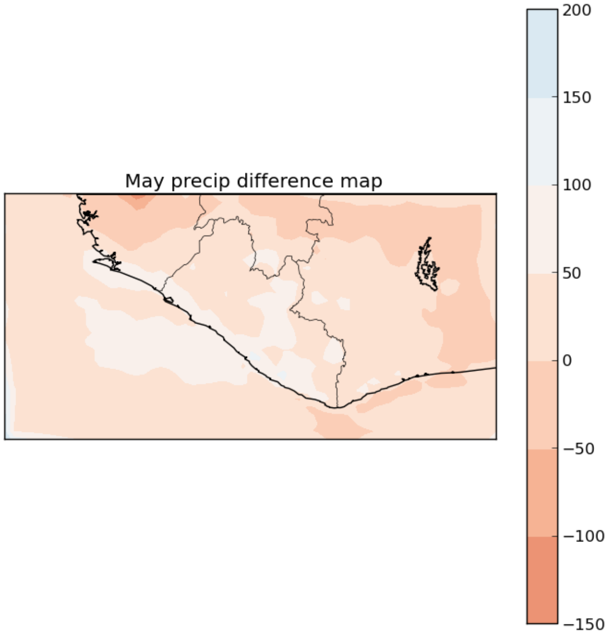


Figure 22 Dynamically downscaled change in precipitation for May (mm)

By June in the dynamically downscaled case, precipitation has begun to increase across much of the country (Figure 23). The slightly drier conditions in May followed by wetter conditions in June may be indicative of a shift in the timing of the monsoonal flow. July continues to show enhanced precipitation across much of the country (Figure 24) 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 25).

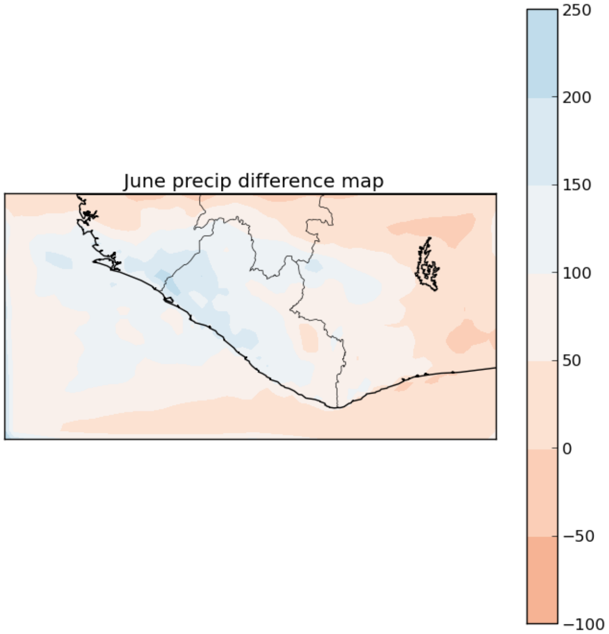


Figure 23 Dynamically downscaled change in precipitation for June (mm)

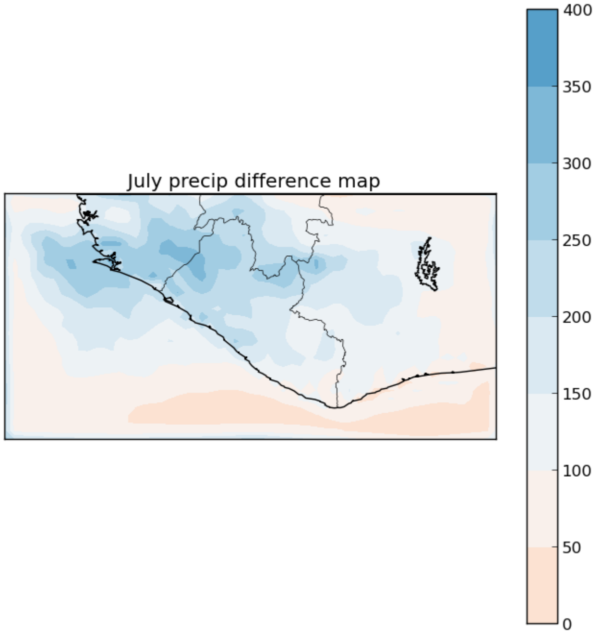


Figure 24 Dynamically downscaled change in precipitation for July (mm)

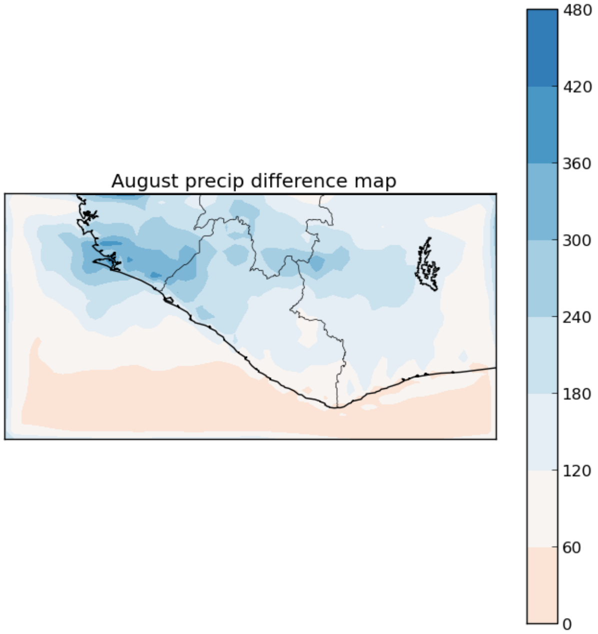


Figure 25 Dynamically downscaled change in precipitation for August (mm)

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 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 14 to Figure 17) with the dynamic downscaling (Figure 22 to Figure 25) 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. To examine the potential impact to vegetation of these competing factors an aridity index was created as the ratio of precipitation to evapotranspiration. 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 down scaling 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 Figure 26). Unlike the statistical downscaling, no areas of major drying (decreased average annual aridity index) were produced by the dynamic downscaling.

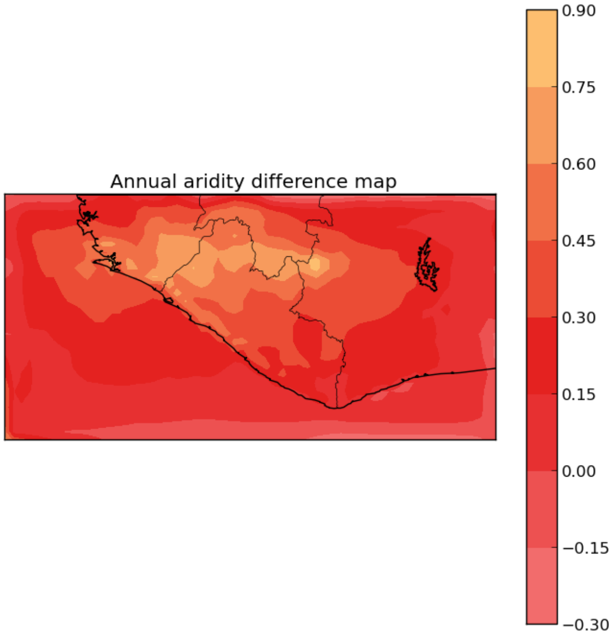


Figure 26 Change in average annual aridity from dynamic downscaling.

SOCIAL VULNERABILITY

For purposes of this assessment, we adopt a “starting point” definition of social vulnerability to climate change, adhering to the Kelly and Adger (2000) definition of social vulnerability. We treat vulnerability as a measurable characteristic present within a population and influenced by multiple socioeconomic and biophysical factors. Many aspects of social vulnerability are generic in that they are common across geographic scales; in contrast, aspects of inherent vulnerability of natural systems are more location specific. As (Brooks, 2003) emphasized, vulnerability only makes sense in the context of a specific system and range of hazards, that is, vulnerability is “place based” in that the scale of vulnerability assessment should match the scale of the decision-making (Schröter et al., 2005). We attempted to integrate information on climate and social and natural systems spatially and used GIS technology to bring them to a compatible scale at the county level. We treat vulnerability as a measurable characteristic present within a population and influenced by multiple socioeconomic and biophysical factors. Our assessment approach is comprised of four main steps: (1) identifying variables that contribute to social vulnerability to climate change on the basis of the academic literature; (2) selecting available socioeconomic indicators that serve as proxies for evaluating these variables; (3) combining the variables into a multivariate-based classification of overall social vulnerability to climate change using principal components analysis (PCA) and factor analysis ; and (4) using GIS to map the factor loadings for the various social Liberia and in relation to natural resources.

In constructing our classification, we tried to use indicators that covered the oft-referenced “four dimensions of poverty”. Those dimensions are income and material needs, health and basic education, rights and empowerment, and social and cultural affiliation and security. Climate variability and change impacts the way that people secure or fail to secure needs that fall into these categories. Obtaining information at the county level on rights and empowerment and social and cultural affiliation and security was difficult; such needs are best assessed at the community level. Nevertheless, within the health area we attempted to get at the notion that poor nutrition and health services compound disease outbreak and contribute to a loss of productive labor during droughts and floods, or other events that may arise as a result of climate change. Additionally, a poor baseline nutrition level or pre-existing poor sanitation practices might indicate that the population is already stressed and will experience more "catastrophic" reductions in this area or experience greater difficulty coping with other climate change related stress given their current existing conditions.

The Social Vulnerability Classification was constructed from 18 spatially referenced variables (Table 6) based upon county-level 2008 census data (CFSNS 2010) or other reports (Sutter and Cashin 2009) similar to work done in Ghana (Stanturf et al., 2012) and applied elsewhere for regional analysis (e.g., Abson et al. 2012). Our analysis of social vulnerability focused on 18 social attributes (12 at the district level from census data including[3]: Displaced Population, Distance to Improved Drinking Water, Distance to Medical Facility, Illiterate Population, Households not involved in Fishing, Households Lacking Furniture, Households with no Livestock, Households Lacking a Mattress, Households with no Poultry, Substandard Housing, Unimproved Drinking Water Source, and Unimproved Sanitation; and 6 specified only at the county level: Dependent Population, Disabled Population, Undernourished Population, Prevalence Stunted Children, Without Access to Free Health Care/Drugs and Without Access to Land). The first step in the analysis was a principle component analysis based on the correlation matrix to determine to what degree the dimensionality of the dataset could be reduced by taking advantage of the likely inter-relationship among the various social traits. The scree plot from the PCA revealed that the social traits do show some inter-relations, but this relatedness is spread across more than just a few principal components. We retained 7 principal components which accounted for 77% of the variance expressed by the original 18 social traits[4]. We then used factor analysis to construct vulnerability classes[5].

	Variable	**Poverty Dimension**	**Spatial Level**	**Data Source**
1	% population that was displaced	Sociocultural Affiliation, Security	District	CFSNS, 2010
2	% population that is illiterate	Health, Education	District	CFSNS, 2010
3	% households that are >20 minutes to drinking water	Health, Education	District	CFSNS, 2010
4	% households that are without an improved water source	Health, Education	District	CFSNS, 2010
5	% households that have unimproved waste disposal	Health, Education	District	CFSNS, 2010
6	% households that are >80 min to rural medical facility	Health, Education	District	CFSNS, 2010
7	% households that do not produce poultry	(Protein)	District	CFSNS, 2010
8	% households that do not produce fish	(Protein)	District	CFSNS, 2010
9	% households with no livestock	Material wealth, (Protein)	District	CFSNS, 2010
10	% households that are without a mattress	Material wealth	District	CFSNS, 2010
11	% households that are without furniture	Material wealth	District	CFSNS,

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[3] Population and household attributes are based on percentages.

[4] Kaiser's rule dictates that only those components accounting for more than the average amount of the total variance be retained in PCA which in the case would dictate 6 components be retained (Wilks, 1995); however, since the scree plot is not showing a natural break at this point we retained 7 principal components.

[5] The p-value on the factor analysis assuming 7 factors was 0.186 which indicates that 7 factors are sufficient to capture the dimensionality of the social dataset.

				2010
12	% households that have substandard housing	Material wealth	District	CFSNS, 2010
13	% population that is dependent	Sociocultural Affiliation, Security	County	CFSNS, 2010
14	% population that is disabled	Health, Education	County	CFSNS, 2010
15	% households that are undernourished	Health, Education	County	CFSNS, 2010
16	% stunted children	Health, Education	County	CFSNS, 2010
17	% households that do not have access to land	Sociocultural Affiliation, Security	County	CFSNS, 2010
18	% households that do not have access to free drugs, medical care, or both	Health, Education	County	CFSNS, 2010

Table 6 Variables used in constructing the Social Vulnerability Classification.

The factor loadings for the various social traits in our vulnerability classification reveal which traits contributed most strongly to each factor (Data in Appendix). Factor 1 is most strongly influenced by Unimproved Drinking Sources, Unimproved Sanitation, Distance to Medical Care, Distance to Improved Drinking Water and the Percentage of the Population that is Illiterate. Factor 2 is driven by availability of protein sources (Lacking Livestock, Lacking Poultry, and Not Involved in Fishing); however, livestock is not purely a protein source as it is also an indicator of affluence. Factor 3 reflects the influence of the Percentage of the Population that is Undernourished which is a county-level variable and the Prevalence of Stunted Children, another county-level variable. Factor 4 is most influenced by the Percentage of the Population that is Displaced and the Lack of a Mattress. Factor 5 comprises the Disabled and Dependent portions of the population. Factor 6 couples the Access to Free Medical Care/Drugs and the Without Access to Land (both county level variables). Factor 7 is most influenced by the Lack of Furniture and Lack of a Mattress. One trait did not show up as dominant contributors to any of the factors, Substandard Housing.

The first 5 factors account for the majority of the variance explained by the seven factors and are the most easily interpreted. Factor 1 can be thought of as a “water quality” factor due to the strong influence of the Unimproved Drinking Sources and Unimproved Sanitation traits (Fig. 12). Factor 2 reflects “food quality” as it is dominated by the three possible protein sources (Fig. 13). Factor 3 reflects “food quantity” as its strongest traits are percentage of population under-nourished and prevalence of stunted children (Fig. 14). Factor 4 reflects the added stress on local resources by “displaced populations” (Fig. 15). Factor 5 groups disabled and dependent populations and reflects a stress on local resources that differs from that of Factor 4 (Fig.16).

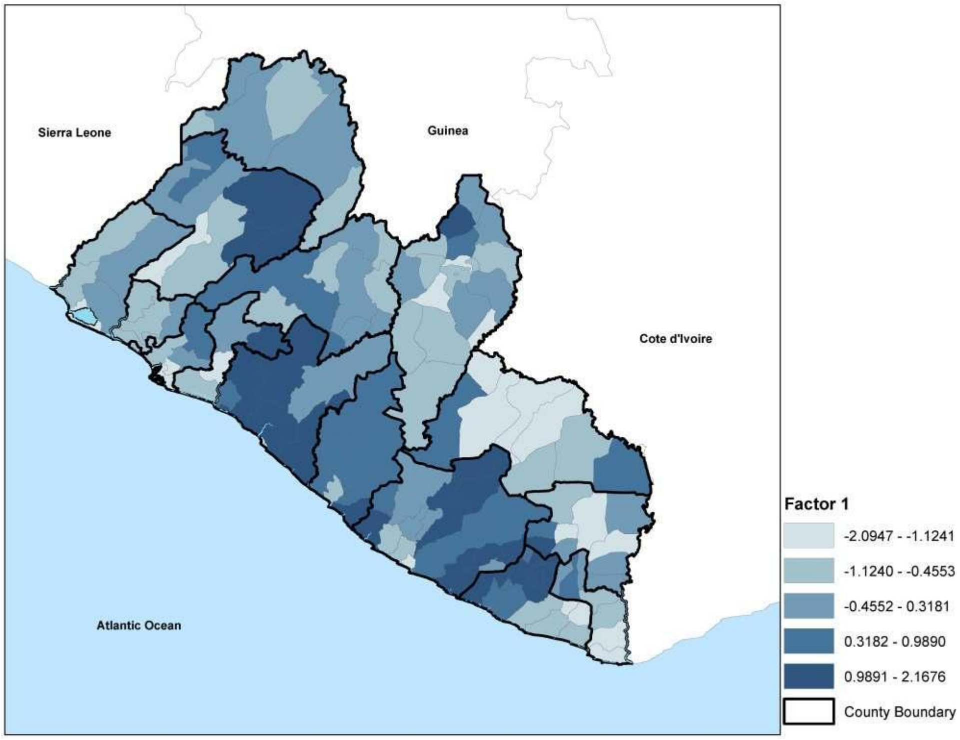

Figure 27 Factor 1 is the water quality factor.

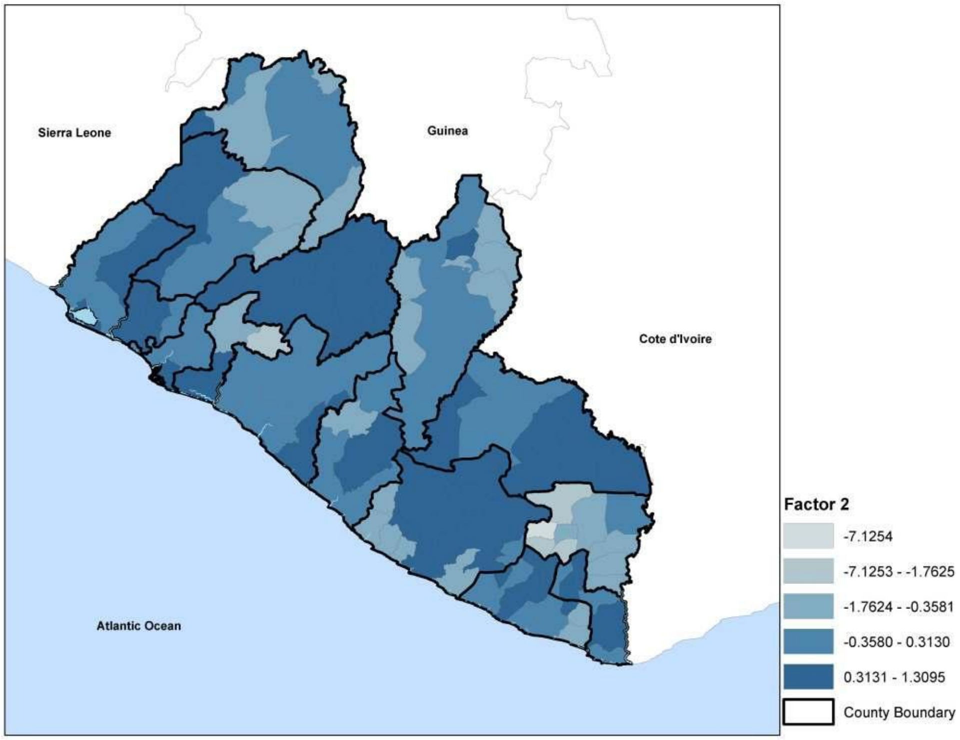

Figure 28 Factor 2, food quality.

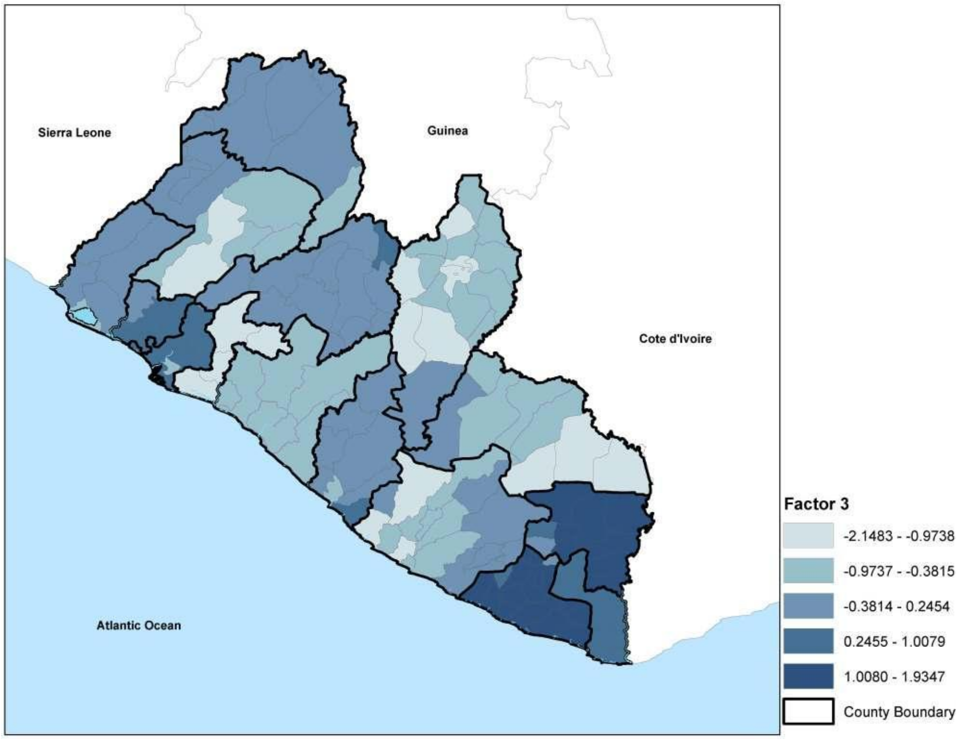

Figure 29 Factor 3, food quantity.

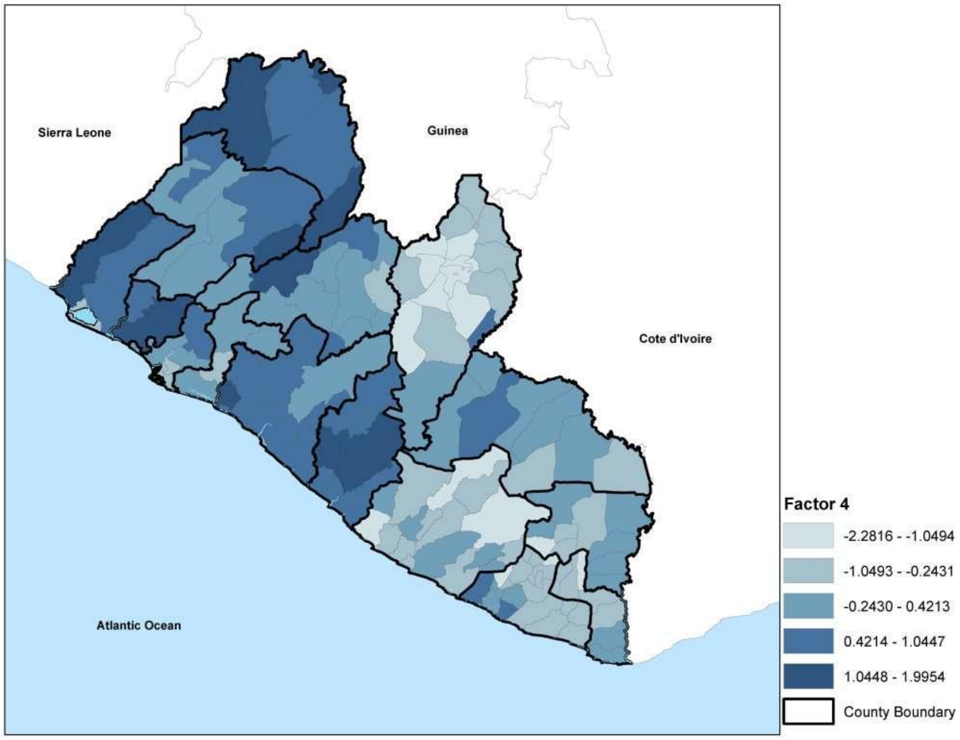

Figure 30 Factor 4 reflects influence of displaced populations.

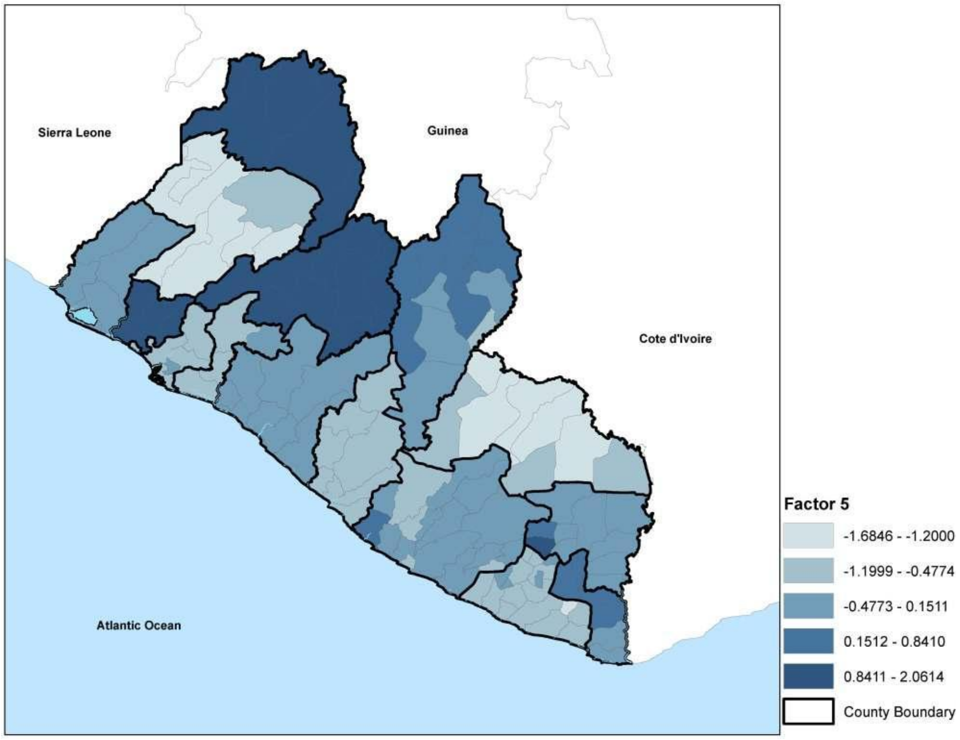

Figure 31 Factor 5 groups disabled and dependent populations.

Factor 1 is the water quality factor due to the strong influence of the Unimproved Drinking Sources and Unimproved Sanitation traits (Figure 20). Factor 2 reflects food quality as it is dominated by the three possible protein sources (Figure 21). Factor 3 reflects “food quantity” as its strongest traits are percentage of population under-nourished and prevalence of stunted children (Figure 22). Factor 4 reflects the added stress on local resources by “displaced populations” (Figure 23). Factor 5 groups disabled and dependent populations (Figure 31) and reflects a stress on local resources that differs from that of Factor 4 (Figure 30).

One key aspect of social vulnerability is food insecurity; this has been assessed at the county level (Figure 32) and the results are similar to Factors 2 and 3 in the present study. Most rural households in Liberia are food insecure, meaning that they lack access at all times of the year to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Nationally, 80% of the rural population was either moderately vulnerable (41%) or highly vulnerable (40%) to food insecurity (GoL 2007). Different rural livelihood profiles provide differing degrees of food security; the most food insecure groups were those involved in palm oil production and selling, followed by hunters and contract laborers.

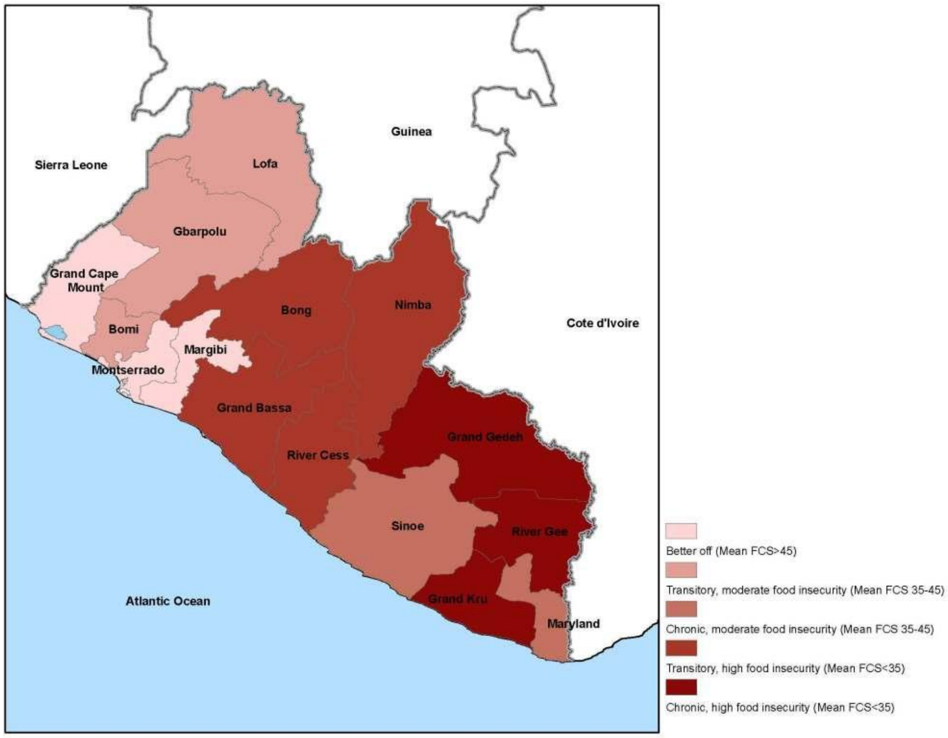

Figure 32 Food insecurity at the county level (Source: GoL Ag Assessment 2007).

The overall social vulnerability of each district was classified through a cluster analysis of the seven factors identified above. The goal of the cluster analysis[6] was to derive some broad characterization of social vulnerability to facilitate discussion. Cluster 1 shows perhaps the strongest overall vulnerability as it shows the most positive scores for among the seven factors with maximum values for Factor 3 (food quantity) and Factor 6 (access to land/free medical care). Water quality and food quality (Factors 1 and 2) also had positive scores, as did Factor 7 (lack of furniture/mattress). Displaced and dependent populations (Factors 4&5) were not found to be critical in Cluster 1. Overall vulnerability (Cluster 1) is greatest in Lofa, Bong, Grand Cape Mount, and Bomi Counties (Figure 33).

Cluster 3 is generally the least vulnerable group as its centroid is negative for all factors except Factors 6 and 7 which are driven by access to land/free medical and lack of furniture/mattress. Cluster 3 is comprised of Montserrado and Grand Cru Counties.

Cluster 4 reflects another very vulnerable group, scoring highest in areas of displaced and dependent populations (Factors 4 and 5) and having positive values for all factors except for Factor 1. Vulnerability is therefore high in River Gee and districts in the northern half of Maryland County.

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[6] Clustering was performed using the k-means clustering algorithm assuming 5 clusters. Membership was well distributed among the clusters as the smallest cluster contained 15 districts and largest 39 districts.

Food quantity (Factor 3) is a concern in Cluster 5 (districts in Grand Bassa, River Cess, most of Sinoe and Gbarpolu, and portions of Margibi, Nimba and Grand Gedeh Counties) but this might be for differing reasons than in Cluster 1 as the factor loading for availability of protein (Factor 2) is much lower suggesting the possibility that in these districts the issue is more about food quantity than quality.

Cluster 2 is most strongly influenced by Factor 1, reflecting the potential importance of water quality to districts in Nimba, Grand Gedeh, Margibi, southern part of Gbarpolu, and mostly urban areas of Sinoe and Maryland Counties.

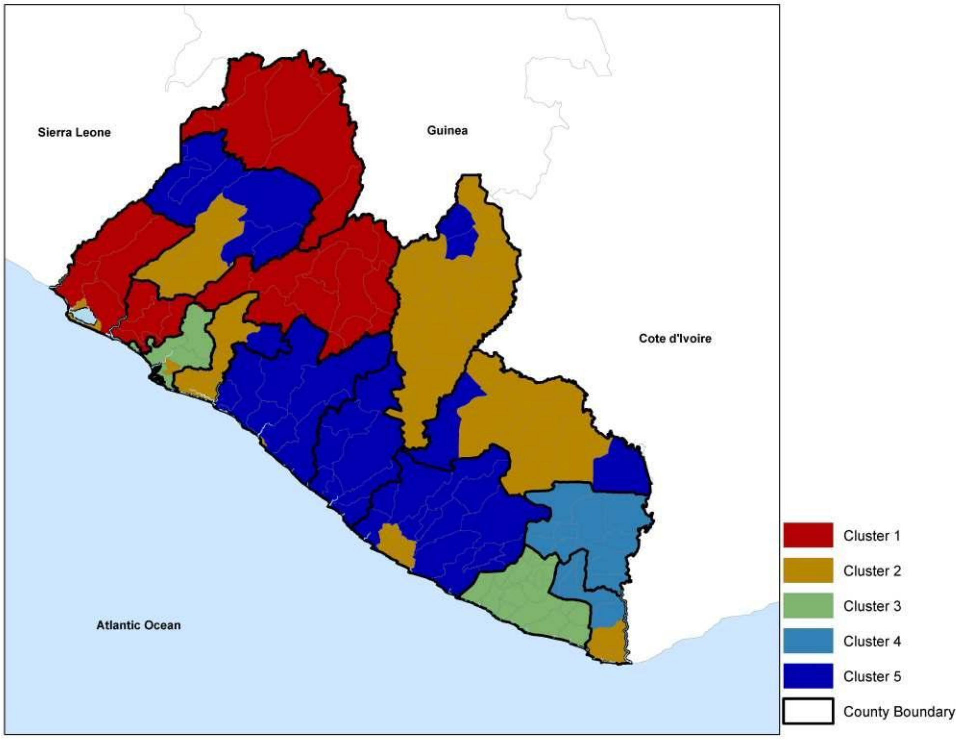


Figure 33 Overall vulnerability clusters.

AGRICULTURE

Most economic sectors declined because of the civil war and its aftermath, resulting in a rise in the importance of agriculture (GoL 2007). The forestry sector peaked during the worst excesses of illegal logging around 2000, but has since declined with the ban on timber exports (now rescinded). Food crop production is the most important source of livelihood (41% of households are engaged in this activity) and cash-crop production is important in Nimba and Grand Bassa Counties. Processing and selling of palm nuts is a key source of income in Lofa, River Cess and Bomi Counties (GoL 2007). Apart from the plantations (rubber, cocoa, coffee and oil palm) the farming system has largely been one of shifting cultivation, with a fallow period of 9–10 years. The farming method includes felling/slashing, burning and planting. Bushmeat is a major source of protein in much of the country. We used census data on household production of various foodstuffs as a surrogate for agricultural production. We mapped the percentages of households within a district reporting production of the main cereal rice; cassava and plantain production are also important food crops.

Rice is the staple food, with over half of the households reported to have produced some rice in during 2005 (CFSNS 2006). This is borne out by our mapping of the percentages of households producing rice in each district (Figure 34). There are basically two systems of rice cultivation: upland rice and swamp rice. The former dominates: data from the CFSNS (2006) indicate that 63% of households fully relied on upland rice techniques, while 17% opted for swampland; 21% used a mixture of both. Techniques differ across Liberia and reflect local agro-ecological conditions. Upland rice dominates in River Cess, Grand Kru and Nimba, while the majority of households in Lofa grow swampland rice only. Lofa County has the highest concentration of developed swamplands in the country as a result of past investment by donor-funded agricultural development projects.

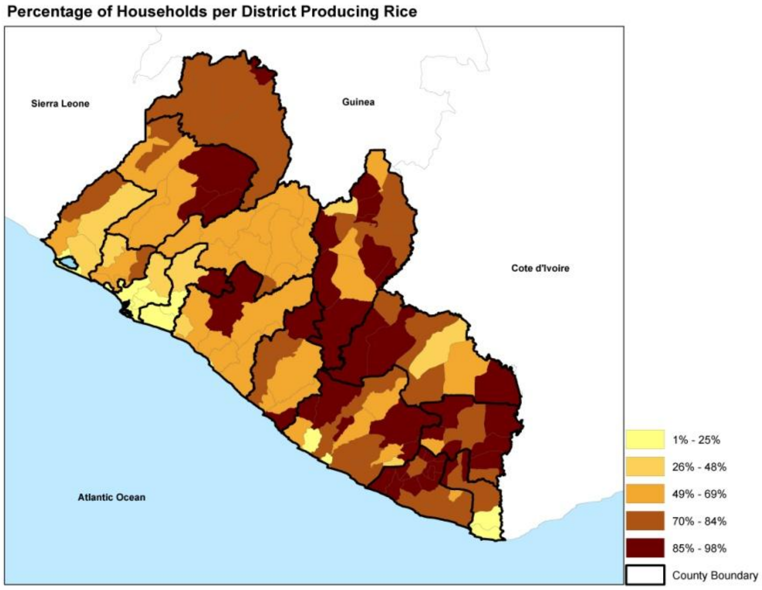


Figure 34 Percentages of households in each district producing rice.

Upland rice cultivation is carried out purely under rain-fed conditions using shifting cultivation, with the rice planted on farms in the same year that fallow or forest vegetation is cleared. Seed is broadcast. The upland farm is a mixed cropping system that usually includes maize, cassava and banana/plantain as well as local vegetables (e.g. pepper and bitter balls). Farm size averages approximately 1.1 ha, and rice yields are between 0.5 and 1.1 mt/ha.

Swamp rice is traditionally grown in inland valleys that have been cleared, usually using hand labor. The rice varieties are usually different from those grown on the uplands and the seed is usually transplanted. The swamps are extensively used for the production of rice in the rainy season and vegetables during the dry season. Other crops, such as cassava, are planted on mounds during the dry season. Farm sizes are usually smaller and yields higher than on the uplands.

Cassava is the second most important food crop (Figure 35) with annual production estimated at 250,000 tons. Its advantages are that it can be planted all year round, the time of harvest is not critical, and it can be stored in the ground. It is therefore very important for food contingency, especially before the rice harvest. It is often planted as a follow-on crop after upland rice is harvested. In addition, cassava leaves are an important vegetable, although harvesting of leaves affects tuber yield (this effect is reduced in the rainy season).

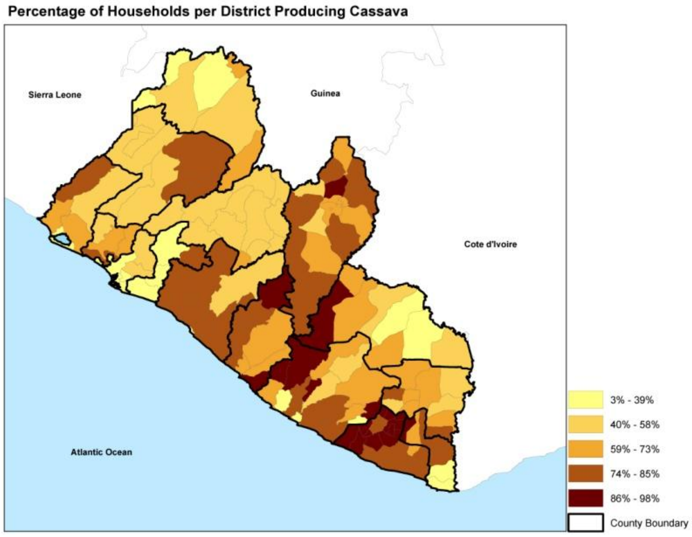
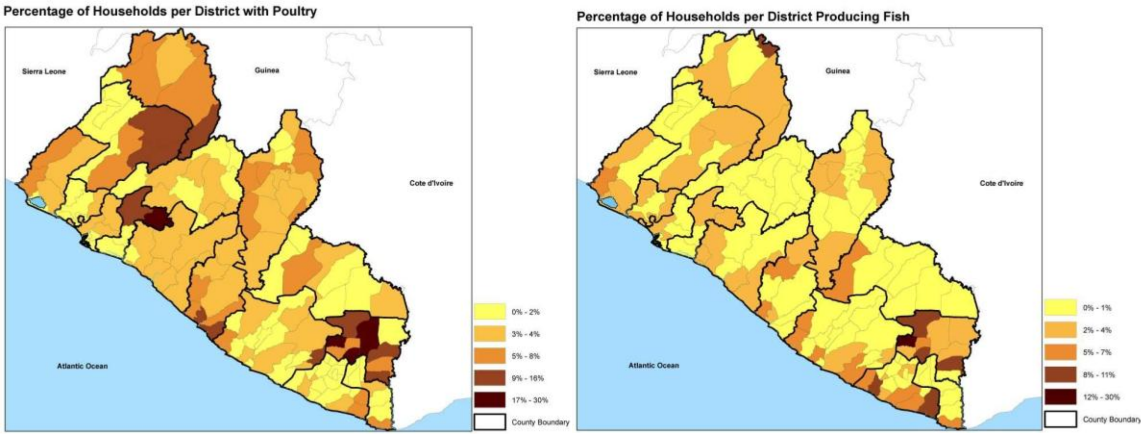

Percentage of Households per District Producing Cassava

Figure 35 Percentage of households in each district producing cassava.

Protein sources such as poultry and fish (Figure 36) were mapped at the district level on the same basis (percentage of households engaged in producing these items).


Percentage of Households per District with Poultry

Percentage of Households per District Producing Fish

Figure 36 Percentages of households at the district level raising poultry or engaged in fishing.

Palm oil is both a foodstuff and a cash crop but the census data do not allow us to differentiate between subsistence and commercial production (Figure 37). Rubber is another cash crop for the smallholder as well as a major plantation crop (Figure 38).

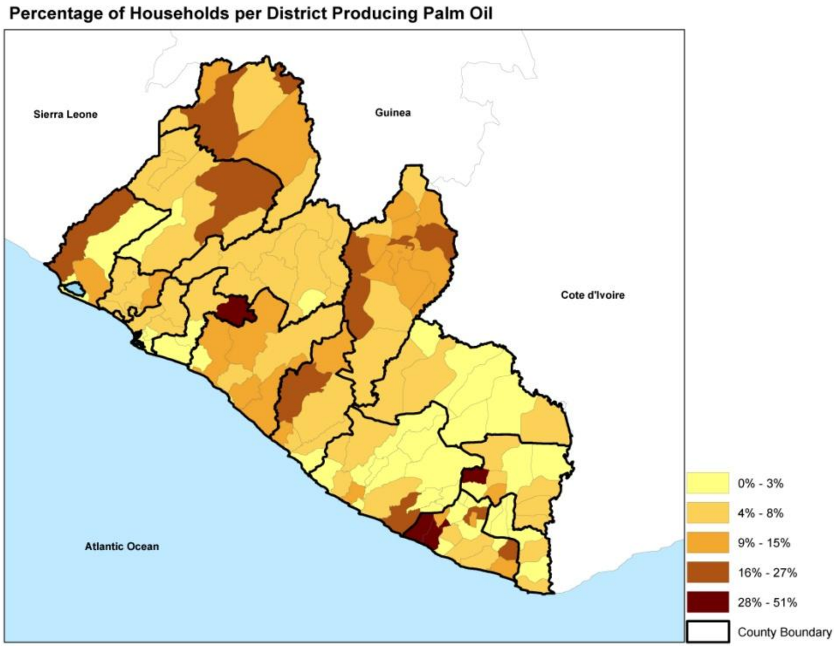


Figure 37 Percentage of households at the district level producing palm oil.

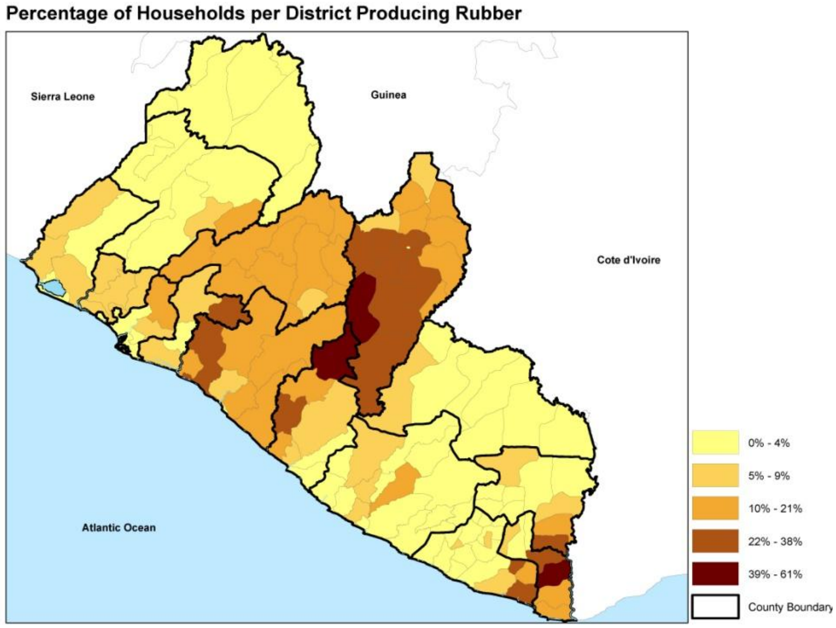


Figure 38 Percentage of households at the district level producing rubber.

NATURAL SYSTEMS

Most natural resources are climate-sensitive; plant and animal species are sensitive to weather extremes, and communities are broadly distributed along climatic gradients. Soil resources are less sensitive to climate extremes but develop over time within a climatic regime characterized by mean values. Thus, climate variability and change potentially could affect these resources and the human communities that depend upon them. We examined resource vulnerability at the national level in terms of current stressors, primarily development pressure on forests and protected areas, overfishing, and climate hazards such as higher temperatures, altered rainfall patterns and sea-level rise. Climate change impacts on natural forested ecosystems, especially protected areas, are exacerbated by short-term stresses from development activity. Many of these stressors manifest throughout the country (e.g., heat stress) but some, such as coastal erosion, are limited to one region. Similarly, some resource systems are impacted by most stressors but in different ways depending on the resource subsystem, such as agriculture (e.g., small holder versus commercial operator).

The government holds the forest resources in trust for the greater good of the population with the Forest Development Authority (FDA) responsible for management, protection, and development. There are 11 national forests, one national park, and one strict nature reserve (Figure 39). Government supervision and implementation of policy, regulations, and the forestry law has been weak, inadequate, or in collusion with illegal operators, leading to many violations, financial misappropriation, and non-payment of the majority of forest fees (FDA 2007). At present the FDA does not have the capacity to regulate wildlife consumption throughout the country (DAI 2008).

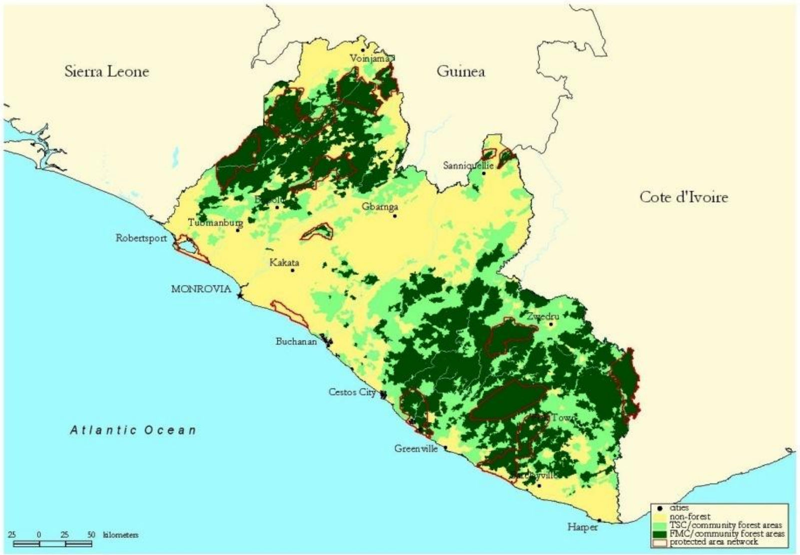


Figure 39 Extent of forests in Liberia and their management classification (Source: FDA 2007).

The largest remaining contiguous block of the Upper Guinean Forest is in Liberia. The forest mainly survived the civil war intact but somewhat degraded (McAlpine et al. 2006) and until recently, commercial logging activity has been minimal throughout the country due to international sanctions imposed during the conflict. The forest in Liberia is home to a number of threatened faunal species including chimpanzee (*Pan troglodytes*), red colobus monkey (*Piliocolobus badius*), Diana monkey (*Cercopithecus diana diana*), pygmy hippopotamus (*Hexaprotodron liberienses*) and the most forest elephants (*Loxodonta africana cyclotis*) in West Africa. Floral diversity is high with 2,900 species of flowering plants, including about 240 timber species. In all, there are about 125 mammal species, 590 bird species, 74 known reptiles and amphibians and over 1000 described insect species (Garnett and Utas 2000).

Rapid expansion of log production and export from 2000 to 2003 to fund the conflict resulted in over-harvesting generally and exploitive harvesting of valuable species resulting in forest degradation (McAlpine et al. 2006). Pit-sawing activities began immediately after the end of civil conflict in 2003 in a largely un-regulated environment and have grown to a market size of >120,000 m^3 of cut wood (Blacket et al. 2009). Fuelwood and charcoal production employ numerous people and remain, by far, the most important energy sources in the country (CFSNS 2010) with electrical infrastructure extensively damaged during the civil war. Similarly, harvesting and sale of bushmeat and Non-Timber Forest Products (NTFPs) make a significant contribution to local income and employment while providing a major share of protein in the average diet (Koffa 2010). Widespread wildlife poaching for bushmeat export to surrounding countries has degraded biodiversity in many areas where forests are accessible (Bennett et al. 2006; Refisch and Koné 2005).

Before the conflict, tree crops were an important component of the Liberian economy, accounting for 22% of GDP in 2005 (DAI 2008). Rubber alone employed 18,500 workers and accounted for 90% of total exports. Although current efforts appear to focus on restoring productivity of rubber and oil palm plantations, future threat to forests from agro-industrial plantation expansion seem likely as there may be economic pressure to expand the area under tree crops, particularly given the Government’s interest in biofuel (oil palm) production. In the past, the conversion of huge areas of Liberia‘s forests into monocultures of rubber and oil palm accounted for the vast majority of forest loss (DAI 2008). Many of the palm oil plantations were abandoned during the war and currently there are an estimated 6,000 ha of palm oil plantations in production and an additional 30,000 ha of abandoned plantations that are available to be refurbished (Lawrence et al. 2009).

There are several estimates of deforestation rates in Liberia with little consistency among them. The FAO estimate from 1990 to 2005 is 22% (FAO 2005). Deforestation drivers include shifting cultivation, small-scale plantation development and small-scale alluvial mining. In a recent forest change analysis, almost all clearing is in the form of numerous small (<10 ha) clearings around towns and roads near towns in the forested regions, which indicates a strong relationship between settlement patterns, road access and forest clearing (GoL 2008).

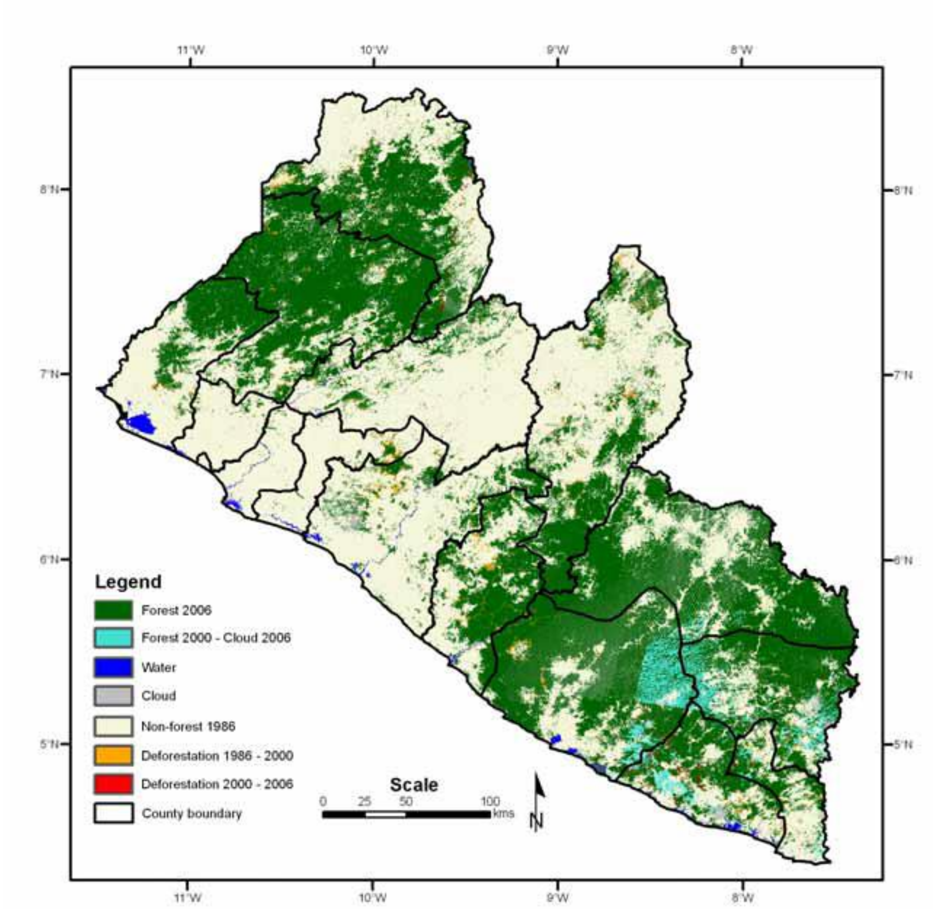
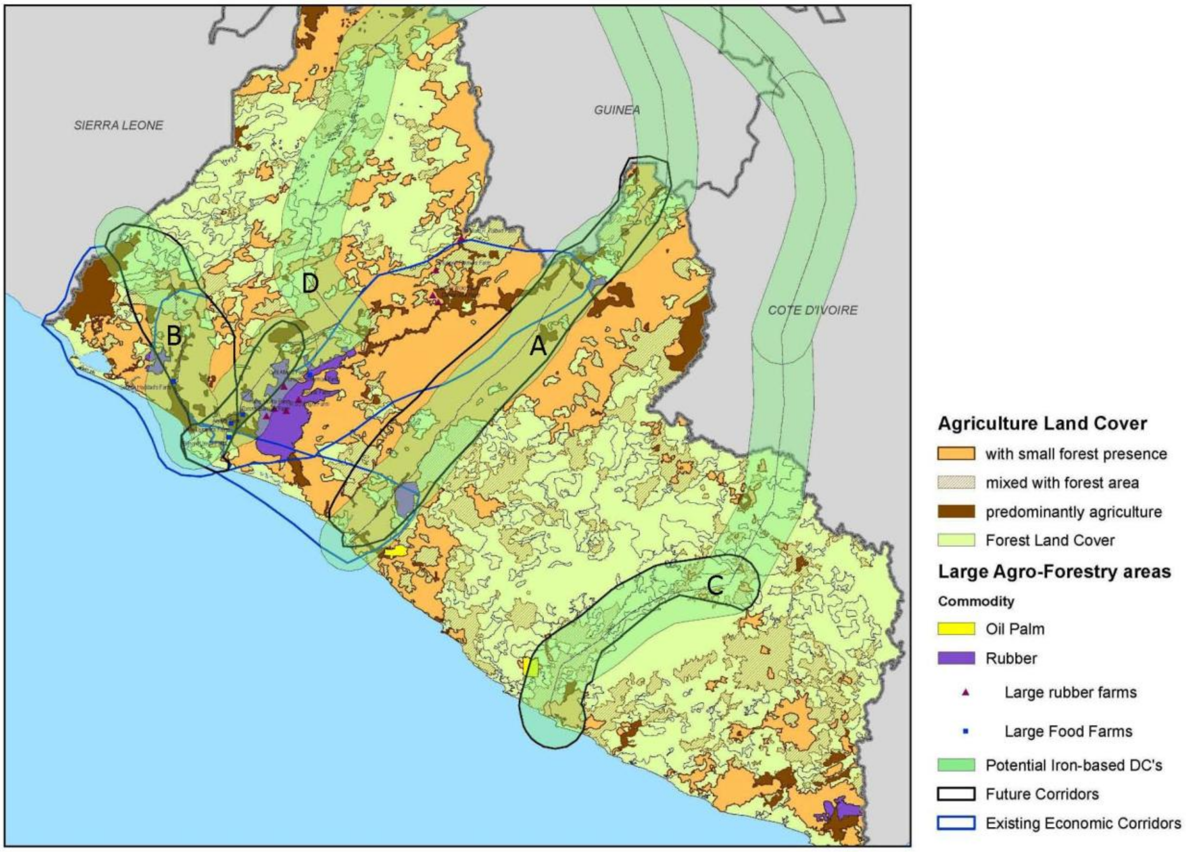


Figure 40 Forest cover and deforestation in Liberia from circa 1986 to circa 2000 to 2006.

Recent estimates of the spatial extent of deforestation utilize data are from Christie et al. (2007) and an unpublished update of this analysis by South Dakota State University, Conservation International and the FDA (Figure 40). Data are from analysis of Landsat data and have a minimum mapping unit of two ha (GoL 2008).

Perhaps the greatest threat to forests and wildlife comes from potential future developments in the mining sector. Liberia is endowed with a variety of mineral resources, both higher value metals and industrial minerals. Iron ore, gold, and diamonds are the principal mineral resources occurring in ancient Greenstone Belts in many parts of the country. The GoL expects industrial and artisanal mining activities to grow rapidly; indeed the GoL is counting on such growth as a means of contributing significantly to employment, income generation, and infrastructure development. The main known iron ore deposits that could catalyze development corridors (i.e., railway-highway-port development) are (Figure 41) the (A) Buchanan–Nimba corridor; (B) Monrovia–Tubmanburg–Mano River corridor serving the Western Cluster deposits at Bomi, Bea Mountain, and Mano River; (C) Greenville–Putu corridor serving the Putu range deposit; and a possible future (D) Monrovia–Wologizi corridor either via the Bong deposit or via the Bomi deposit to the Kpo deposit and on to the Wologizi deposit (MPEA 2008).

The Buchanan-Nimba port-rail corridor has been rehabilitated and is serving the Nimba deposits in Liberia and potentially Kitoma. There is a strong rationale for extending the railroad regionally to serve deposits across the border, the Guinean Nimba, Diake, and Belekoyo deposits and farther north, the enormous Simandou deposit. For the Greenville-Putu port-rail corridor, the initial prospect is for a railway to be built from Greenville on the coast to the Putu Range in Grand Gedeh County. Once that railway is built, mining for iron ore near Man in Côte d'Ivoire and nickel deposits farther north in Guinea may provide incentive for extending it into a regional railway.



(Source: MPEA 2008)

Figure 41 Potential development corridors (A) Buchanan-Nimba; (B) Monrovia-Tubmanburg-Mano River; (C) Greenville-Putu; (D) Monrovia-Wologizi.

A high degree of geographic overlap exists between mineral deposits and exploration permits and the protected area-forest reserve network. If exploitation occurs within these areas as expected, the potential to significantly affect biodiversity and forest cover should be considered extreme. Forest destruction and wildlife poaching will be locally extensive and permanent. Other potential environmental impacts include among others: siltation of reservoirs and rivers, ground and surface water pollution, and habitat fragmentation. The impact of over 100,000 artisanal miners operating in Liberia, including 6,000 in Sapo National Park alone, may have individually insignificant effects on biodiversity and tropical forests but cumulative effects are significant. Further, development of the transportation corridors will open up previously inaccessible areas to commercially-oriented farming and in-migration from surrounding countries.

FISHERIES

The fisheries of Liberia, consisting of a marine and inland component, are important to the future of Liberia for several reasons. The fishery provides fulltime livelihoods for thousands of Liberians and perhaps tens of thousands more on a part-time basis (Figure 42). The fishery also could be a potential source for foreign trade. Importantly, fisheries provide a relatively cheap source of animal protein for the Liberian population, being cheaper than alternatives like livestock or poultry. The fisheries sector is estimated to provide about 65% of the animal protein needs of the country and plays an especially important role while the livestock industry is still being re-established. The contribution of the fishery to the agricultural GDP is about 12% and to the national GDP of Liberia is 3.2% at producer prices (DAI 2008, FAO 2011). Estimated per capita supply of fish however is low (4.33 kg/yr) compared with 14 kg recorded in the 1980s, creating a substantial demand gap (FAO 2011). Much of consumed fish is apparently imported (e.g., sardines, snappers, groupers) from the marine fisheries of Morocco, Spain, and neighboring countries.

Unfortunately, reliable information on the inland and marine fishery is sketchy and estimates of vital statistics (e.g., annual catch, effort, aquaculture production) are at best of uncertain reliability. DAI (2008) reported that fisheries catch data collected by the Bureau of National Fisheries is not national in scope, and the data are often inaccurate and are not analyzable or interpretable for use in management. Even catch statistics reported by observers assigned to fishing vessels (apparently initiated in 2007) are suspect because of the poor salaries of the observers and the suspected collaboration of the observers with boat captains to carry out illegal, unreported, and unregulated fishing (Togba 2008). Further, no in-depth or regular studies of the country’s marine and freshwater resources are available (FAO 2011).

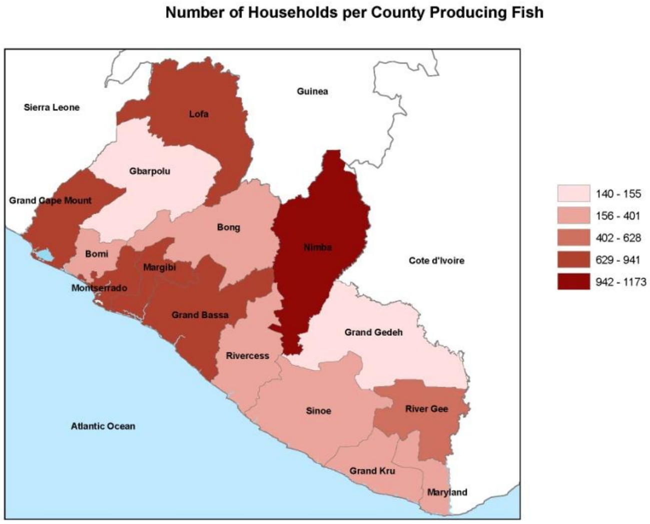


Figure 42 Number of households per county producing fish.

Information on the distribution and abundance of fishes, both inland and marine, is nonexistent, and no stock assessment has been attempted in at least 20 years. Research facilities are lacking to document the ecological and physical factors affecting marine productivity, pollution levels, nutrient loads, or species diversity and exploitation rates (DAI 2008). An acoustic survey in 1984, apparently the last such undertaken, of marine resources estimated total fish resources (biomass) of about 800,000 metric tons of pelagic and demersal species (FAO 2011). The Bureau of National Fisheries, however, believes that demersal species are over-exploited by both commercial and artisanal fisheries (DAI 2008). The Bureau also estimates that the annual catch in the Exclusive Economic Zone (about 186,000 km^2) is much higher than reported by licensed industrial vessels. Poaching (or pirate fishing) is apparently rampant because no monitoring, control, and surveillance system is in place. The Bureau conservatively estimates >250 pirate industrial fisher ships are operating in Liberian waters especially at night. The majority of these use illegal fishing techniques (e.g., small mesh size nets). These boats often operate within the 3-mile limit reserved for artisanal fishers and compete with those fishers for demersal species (DAI 2008).

Nationally, first steps are being undertaken to curb illegal fishing. In 2008, a 60-day Marine Control and Surveillance Project, a joint venture of the Ministry of Agriculture and the Bureau of National Fisheries, resulted in the arrest of several pirate ships. Liberia also plans to engage with the International Maritime Organization‘s security division illegal fishing program, aimed at 25 countries in West and Central Africa. This program links local coastguards with Interpol, the FAO, UNHCR, insurers and other partners, and will include action against illegal fishing (DAI 2008). Recent media reports in Liberia indicated a temporary moratorium (through March or April 2011) was put in place on issuance or renewal of fishing licenses by the Minister of Agriculture to set the stage for application of a set of newly enacted fisheries regulations (Daygbor 2011, The Inquirer 2011). The regulations, which meet international standards and protect the environment, have been approved by the GoL. The rules spell out license fees, give broad boarding and search powers to fisheries inspectors and observers in regard to any vessel suspected of conducting fishing operations in or outside Liberian waters. The regulations also extend the inshore exclusive zone from 3 to 6 mi; the inshore zone is restricted to artisanal and semi-industrial vessels <90 ft in length. Harmful fishing methods are also prohibited (e.g., poison, explosives, small mesh sizes). In a media report, the coordinator of the West Africa Regional Fisheries Project indicated Liberia is an island among countries that have already depleted their marine fishery stocks (e.g., Ghana, Sierra Leone). The coordinator further argued that failure to stop overfishing and harmful practices would place Liberia in a similar situation (FCWC 2011). The initiative to improve governance, control, and economic impact of fisheries in Liberia is coordinated by West African Regional Fisheries Project, a $US 14 million project of the World Bank and Global Environment Facility Fund.

The national fishery has three main subcomponents: marine fisheries, consisting of industrial and artisanal sectors; a mainly artisanal inland, freshwater fishery; and aquaculture, operating generally on a subsistence level. The marine fishery, especially the industrial component, is the most mechanized, processing and holding fish via freezing at sea for domestic consumption (FAO 2011, Togba 2008). Crustaceans (e.g., shrimp) are packaged and frozen for export to Europe and the United States. In general, the fishing industry lacks the infrastructure and equipment to process export quality fish products. The inland fishery is primitive but is estimated to contribute 25% of the fish consumed by the rural population. Aquaculture is primarily practiced on a subsistence level consisting of pond-based management of mostly tilapia. Hatcheries, established with help of the European Union and located at Klay (Bomi County), Douyee Town (Grand Gedeh County) and Salaya (Lofa County), suffered from neglect and near ruin during the conflict years but are apparently again producing fingerlings. Pre-war production was estimated at 29 t, and production is reported to have increased from 22 t in 200 to 38 t in 2004. An estimated 60% of the total domestic fish catch is landed by artisanal marine and inland fishers. Most of the artisanal catch is preserved by salting, smoke drying, and fermenting (FAO 2011).

The industrial fishery, which provides about 17% of the sector’s employment, consists of a relatively small fleet of trawlers (20-52 m long, average crew of 17) which exploits pelagic and commercial species (EPA 2007, DAI 2008, Togba 2008, FAO 2011). In 2004, eight industrial companies operated about 28 trawlers, which included eight Chinese paired benthic trawlers (subsequently these trawlers were banned from legal fishing) (Togba 2008, FAO 2011). In 2008, the number of registered trawlers was 36 (Togba 2008). The catch statistics, although admittedly of uncertain reliability, suggest a downward shifting trend from 4,493 metric tons in 1999 to 2,894 metric tons in 2008. Also, fish imports increased from 9,994 metric tons in 2007 to 13,978 in 2008 (Togba 2008). By about 2008, 14 fishing companies legally operated in Liberia (DAI 2008). Six of these engage in industrial fishing on the high seas, using freezing techniques. Eight other companies, operating 30-40 licensed fishing vessels (including the eight paired trawlers) had a combined gross registered tonnage of about 5,000 tons. The Bureau of National Fisheries, however, contends catch figures are misreported and strongly suspects that some vessels engage in illegal transshipments at sea where catches are repacked and declared as imports.The Bureau estimates $US10-12 million is lost to Liberia through illegal fishing each year (DAI 2008).

The artisanal fisheries lands about 40-60% of the total domestic catch. Most fishers in the country including fishers, fish mongers, and processors are involved with the artisanal fishery, which represents about 80% of employment in the sector, many in the artisanal fishery are women who process and market the fish.The fishery employs a reported 13,000 fishers and about 18,000 fish mongers (processors) living in 139 communities in coastal counties and deploying 3,500 canoes of which 8% are motorized, but the Bureau estimates another 8,000 unlicensed foreign artisanal boats operate in Liberian waters (DAI 2008, Togba 2008). As in the industrial sector illegal gear and methods are reportedly commonly used in the artisanal fishery (e.g., organic and chemical pesticides, dynamite, small mesh sizes), raising the specter of over exploitation. The largest number of canoe fishers operates out of Montserrado and Grand Bassa counties (DAI 2008).

The fleet consists of three primary types of canoes (EPA 2007, DAI 2008, FAO 2011). The indigenous Kru canoe (1-3 person crew) is a dugout type about 7 m in length, powered by small outboard engines (e.g., 7 hp), paddle, or sails. The Kru fishers deploy hook and long lines and gillnets. The Fanti and Popoe fishers dominate the artisanal fishery, using larger motorized canoes. The Fanti canoes are large (12-15 m), often are powered by large (25-45 hp) engines, and deploy ring and purse nets for small pelagic fishes or large gillnets designed for particular species and seasons. The Fanti canoes are estimated to contribute about 40% of all artisanal landings. The Popoes use beach seines (200-800 m long) using small dugout canoes (5-7 m) and a 1-2 person crew (FAO 2011). Most of the larger canoes operate within 10-50 nautical miles of shore.

Constraints

The fishery sector is burdened with constraints which have impeded development for decades. Until recently (see previous) Liberia lacked a fishery policy and national fishery development plan (FAO 2011). Although seemingly having the appropriate overall bureaucratic structure, the Bureau of National Fisheries is bereft of institutional capacity in every area (e.g., staff expertise, training, extension, data collection and analysis, research, monitoring), and lacks the budgetary means to accomplish its mission. DAI (2008) and the West African Regional Fish Project (The Inquirer 2011) concluded the BNF under current limited staff will never be able to accomplish the mandates under the new fishery policy and legislation. Only one Bureau agent is stationed inland to monitor the large inland artisanal fishery, and no boats or motors are available to monitor or control marine fisheries. Despite improved and somewhat comprehensive fishery regulations and operational rules, there is no effective and consistent monitoring, control, assessment, or enforcement capacity. According to media reports, the Coast Guard of the Armed Forces of Liberia is being restructured and trained to use eight donated tactical boats (from the United States) to begin policing smuggling and illegal fishing (Daily Observer 2010), but their duties will go beyond policing of fishery and it is yet to be seen how effective that effort will be. In addition, the country lacks fishery harbors to ease unloading of the catch and supply essential equipment and supplies. The same lack of infrastructure applies to artisanal landing sites, where fish processing is still done on a primitive basis (e.g., fish smoking) and road access to fishing communities tends to be poor. Locally produced fish are also subject to high import duties and landing charges, although how often or consistently the duties are actually collected is uncertain. The operational costs of the artisanal fishery are relatively high because of the high costs of inputs (e.g., fishing gear, motors, fuel) caused in part by high import duties. Finally, the fishery lacks a well-established means of establishing credit and acquiring loans.

The aquaculture sector suffers from a paucity of individuals trained to engage in aquaculture, a lack of quality fingerlings for stocking, lack of quality fish feed, and inadequate irrigation systems for sustained production (FAO 2011). Training consists primarily of short-term workshops or seminars conducted by local or international NGOs pursuing fishery related projects. Within Liberia, no institutions apparently offer training in fisheries and fishery courses are apparently not a mainstay in the university system.

COASTAL AREAS

Liberia has a 565-km long coastline, and much of the population lives in coastal cities. Coastal erosion is a recognized, widespread problem and concern along most of the Liberian coastline (e.g., EPA 2007, DAI 2008). Although quantified estimates of coastal recession are apparently unavailable direct observation confirms the recession of beaches and loss of ocean front structures or even whole villages. Coastal erosion has been severe in Monrovia, Buchanan, and Greenville. During 1981 to 1997, about 100 m of beaches have reportedly been lost (EPA 2007). DAI (2008) reported current beach erosion rates are as high as 3 m/yr with ongoing structural damage and loss. The underlying rates of erosion are likely primarily related to natural conditions (e.g., geology, longshore currents, wave action), but recent human interventions (e.g., uncontrolled sand mining, vegetation destruction, dams, poorly placed breakwaters and ports, groynes, or gabions,) also likely have accelerated or directly caused coastal erosion in all these areas.

Unregulated beach sand mining is one of the most serious threats to the coastline and marine environment in the country. Sand mining changes in the balance of littoral sand transport, blocking the natural sand drift. The sand pits cause a slight embayment of the shoreline due to localized recession. The embayment serves as a void, which must be filled before the sand moves along the coast. Sand is trapped by the recessions, reducing its westward flow. Sand downstream from the flow is not replaced thus exacerbating shoreline erosion. In some areas, beaches are being lost at an estimated rate of 3 m/yr with concurrent property destruction.

The biggest threat to Liberia‘s mangroves is urban expansion and accompanying landfills, particularly in Monrovia. This expansion began during the civil conflict when many displaced people established landfills in Mesurado and Marshall Mangrove wetlands, causing large areas of mangroves to be destroyed (and to be used as dumps or for sewage disposal). The process continues today; Liberia‘s burgeoning post conflict economy and increased population have overwhelmed the original planned land area for Monrovia and other beach cities; originally made to accommodate 350,000 persons, Monrovia‘s now has a population of over 1 million. Mangroves are being degraded due to over cutting for fuelwood, charcoal and construction poles. However, mangroves can usually recover from these activities as they propagate vegetatively, although FAO (2006) reports that *Rhizophora racemosa* seems to have been eliminated in some places by extensive felling. There is no information about the impact of these activities—and secondary mangrove forest—on biodiversity.

CLIMATE CHANGE EFFECTS

The major findings for Africa of the Fourth Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC) confirmed earlier reports, including a warming trend since the 1960s (Boko et al., 2007). In West Africa, rainfall has declined 20 to 40% (average of 1968-1990 as compared with 1931-1960), although the decline in the tropical rainforest zone was only 4% (Malhi and Wright, 2004). Despite advances in our understanding of the complex mechanisms driving rainfall patterns, much uncertainty remains. Drought, a manifestation of extreme rainfall variability, has long been a feature of the continental West African climate with severe and long-lasting impacts on natural and social systems. The decline in rainfall from the 1970s to the 1990s, for example, caused a 25-35 km southward shift of the savanna zone (with loss of grassland and woodland and displacement of human populations) (Gonzalez, 2001). Besides long-term climatic trends and extreme events, ecosystems in West Africa have been degraded by human activity, which often interacts with climate (Taylor et al., 2002; Reich et al., 2001). Major stressors (drivers of degradation) are deforestation, wildfire, and soil erosion in upland areas and overfishing in coastal areas.

Neither the Third nor Fourth Assessment Report of the IPCC reached a consensus regarding the sign or magnitude of predicted changes in precipitation over West Africa during this century (Hulme et al., 2001; Bernstein et al., 2007). Coarse resolution GCMs have difficulty describing the West African Monsoon. This is not surprising considering the wide range of mechanisms for variability acting at various scales of time and space from global teleconnection patterns related to ENSO (Caminade and Terray, 2010) or the Atlantic Multi-Decadal Oscillation (Shanahan et al., 2009) to the coupling of soil moisture to intra-seasonal variability (Lavender et al., 2010). Druyan (2011) provided a convincing argument for the need of more detailed (higher resolution) modeling to properly capture critical processes in this region. Our results illustrate the uncertainty in climate change projections, especially for future precipitation.

ARIDITY INDEX

Aridity is a numerical indicator of the degree of dryness of the climate at a given location and can be used to identify regions that suffer from a deficit of available water which could impair the agricultural productivity of an area. The United Nations Environment Programme defined aridity as the ratio of precipitation to potential evapotranspiration (PET) in their World Atlas of Desertification (UNEP 1997). We constructed an aridity index from the statistical down-scaling from CCM3 as the ratio of precipitation to potential evapotranspiration (PET) in order to incorporate the temperature effect with precipitation. PET is calculated using the temperature based method of Thornthwaite-Mather (1957). In the current study, this ratio is multiplied by 100 so that the resultant index can be represented by an integer value. An aridity value of 100 reflects a state of balance between precipitation and PET; a value less than 100 indicate areas where water loses through PET exceed the amount of water supplied through precipitation.

To compare current conditions to climate projections in 2050, we calculated the aridity index for both years and subtracted the value in 2050 from the current value; a negative value of the change in aridity means the climate in 2050 will be “more arid” relative to current climate. The index is mostly driven by temperature change because in most of Liberia, precipitation exceeds PET. The aridity index identified areas that will be “drier” in 2050 (Fig. 27). The change in annual aridity between current and 2050 more clearly shows areas of potential vulnerability to drier conditions (Figure 43). These areas appeared to be consistent with areas of historical drought, according to (Rojas et al., 2011).

According to the projected change in the aridity index calculated using the statistical downscaled climate data (Figure 44), there are four areas in Liberia that will be “drier” (more arid) by 2050. The most negative values are a region from Grand Cape Mount (except right at the coast) through River Cess, Montserrado and coastal Margibi (including Monrovia). Another region stretches from east to west beginning in southeast Grand Bassa, River Cess, west Sinoe to River Gee counties. Two other clusters have only slightly negative values, one in Gbarpolu and another in Nimba. Much of the change in the aridity index is caused by higher temperatures, especially at night. The annual average daily high temperature in Liberia is projected to increase less than 2 ^{o}C but in the interior, annual average daily low temperatures will increase by more than 2 ^{o}C (Figure 45).

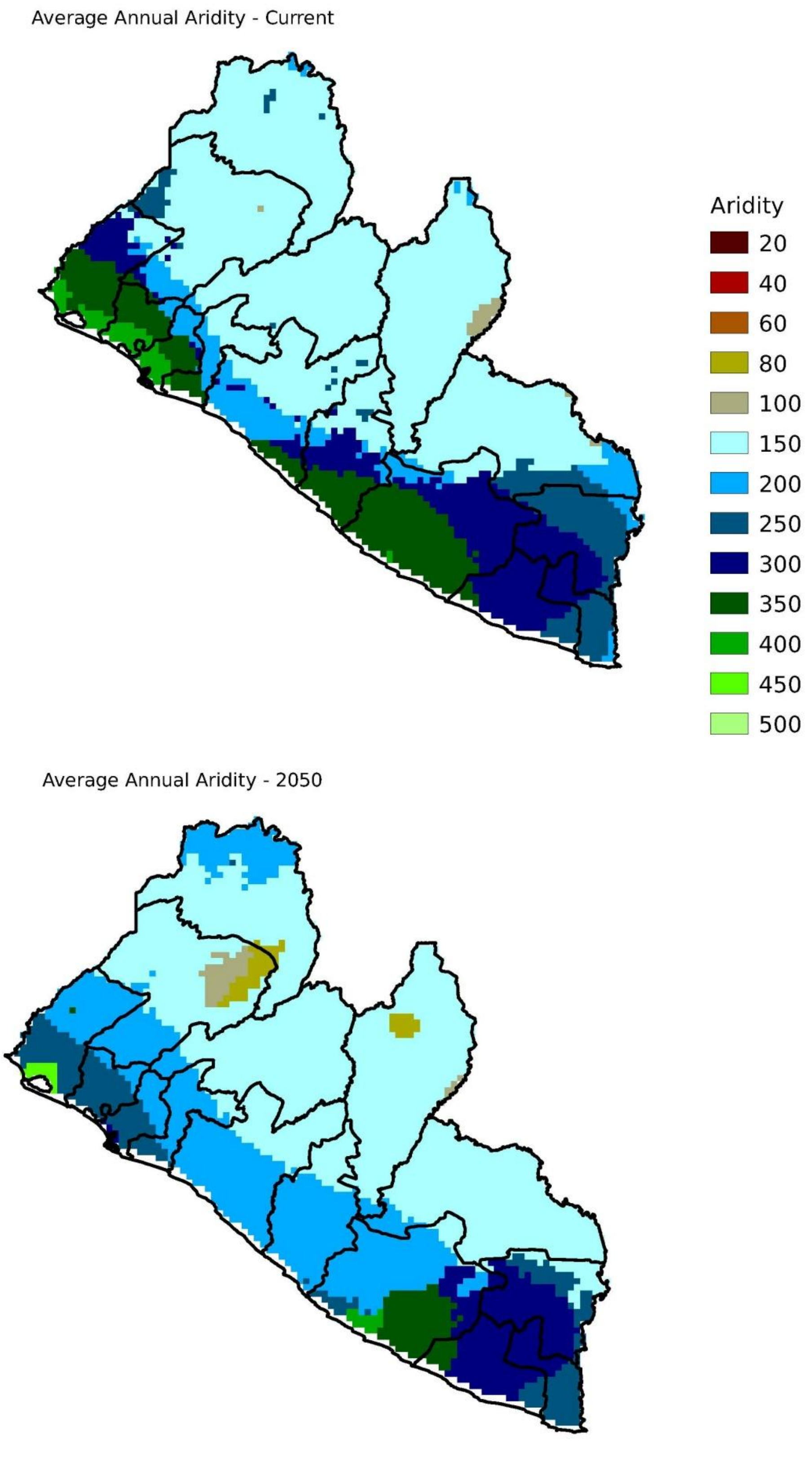


Figure 43 Average annual aridity, current and projected to 2050.

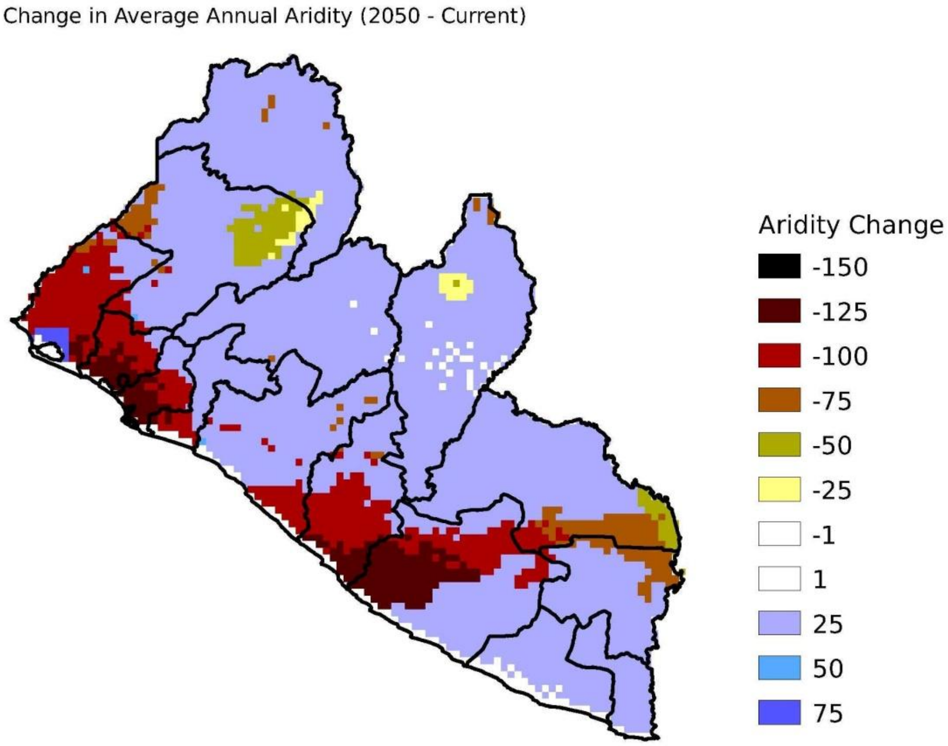


Figure 44 Change in aridity, current vs. 2050.

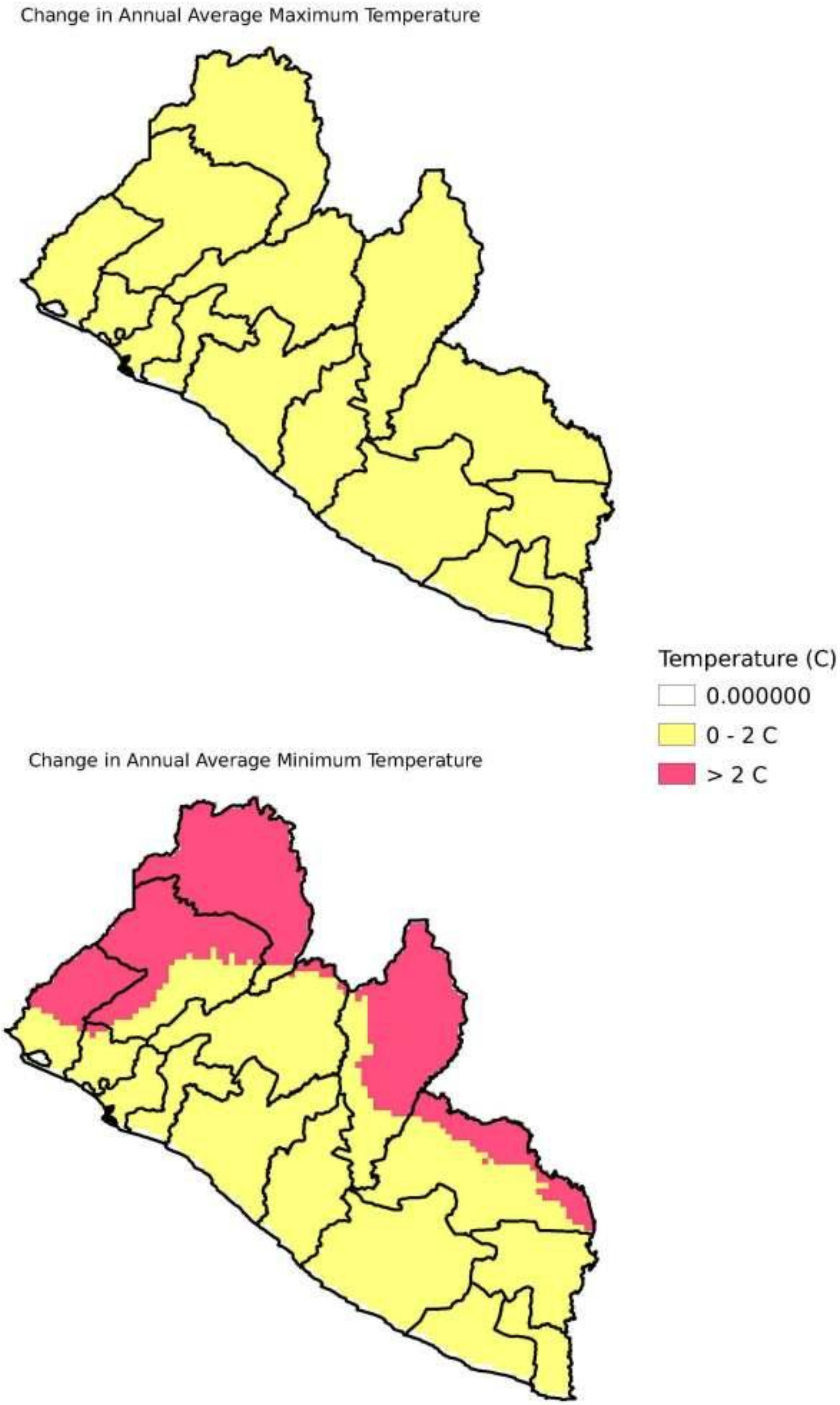


Figure 45 Changes in annual average monthly maximum and minimum temperatures.

Of greater concern to farmers than average values are the monthly changes, especially around the onset and end of the rainy season. The monthly comparisons of current and projected aridity in 2050 are shown in Figure 46 to Figure 57; in these maps, precipitation and potential evapotranspiration are balanced at 100; more arid conditions are indicated by values less than 100. The areas in white are beyond the color scale, indicating areas of extremely low aridity (i.e., precipitation greatly exceeds PET). Examining the monthly aridity maps may give the impression that the annual aridity change map (Figure 44) is invalid. For example, Grand Cape Mount County on the annual aridity change map is shown as one of the areas of greatest aridity change in the future yet the June (rainy season) aridity change map indicates the lowest aridity. It is important to remember that the change map is relative to current conditions; it is the projected aridity map that indicates what future conditions will be. Because Liberia in general is a high rainfall country and temperatures are high, the change may be more important than the actual level. Thus, examining the monthly aridity maps for the northern portion of Grand Cape Mount County shows a decrease in the index in every month except September, which is the same. Even though the projected 2050 aridity index is above 100 in all months of the rainy season (May to September), the area will be “drier” than current conditions.

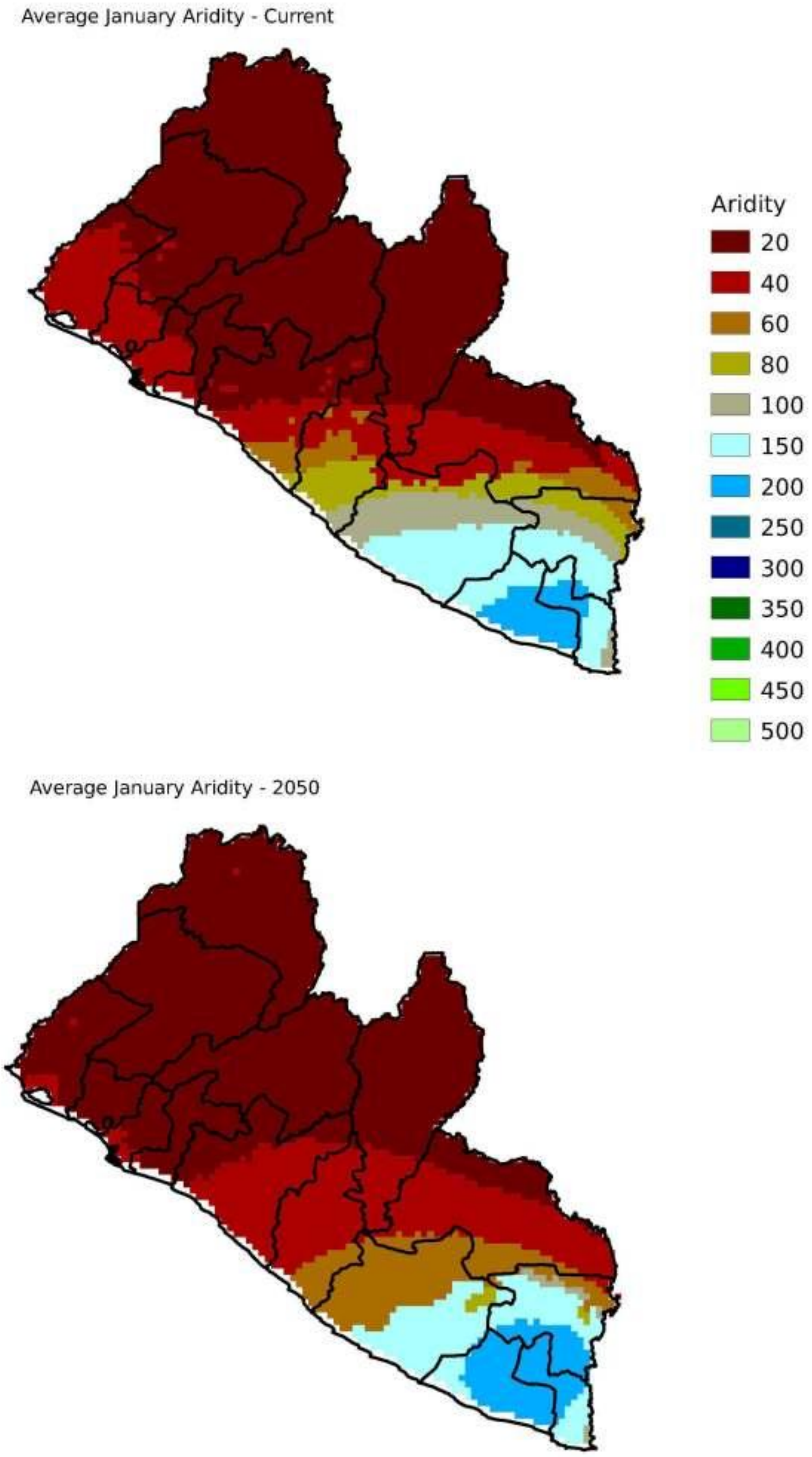


Figure 46 Average January aridity, current and 2050.

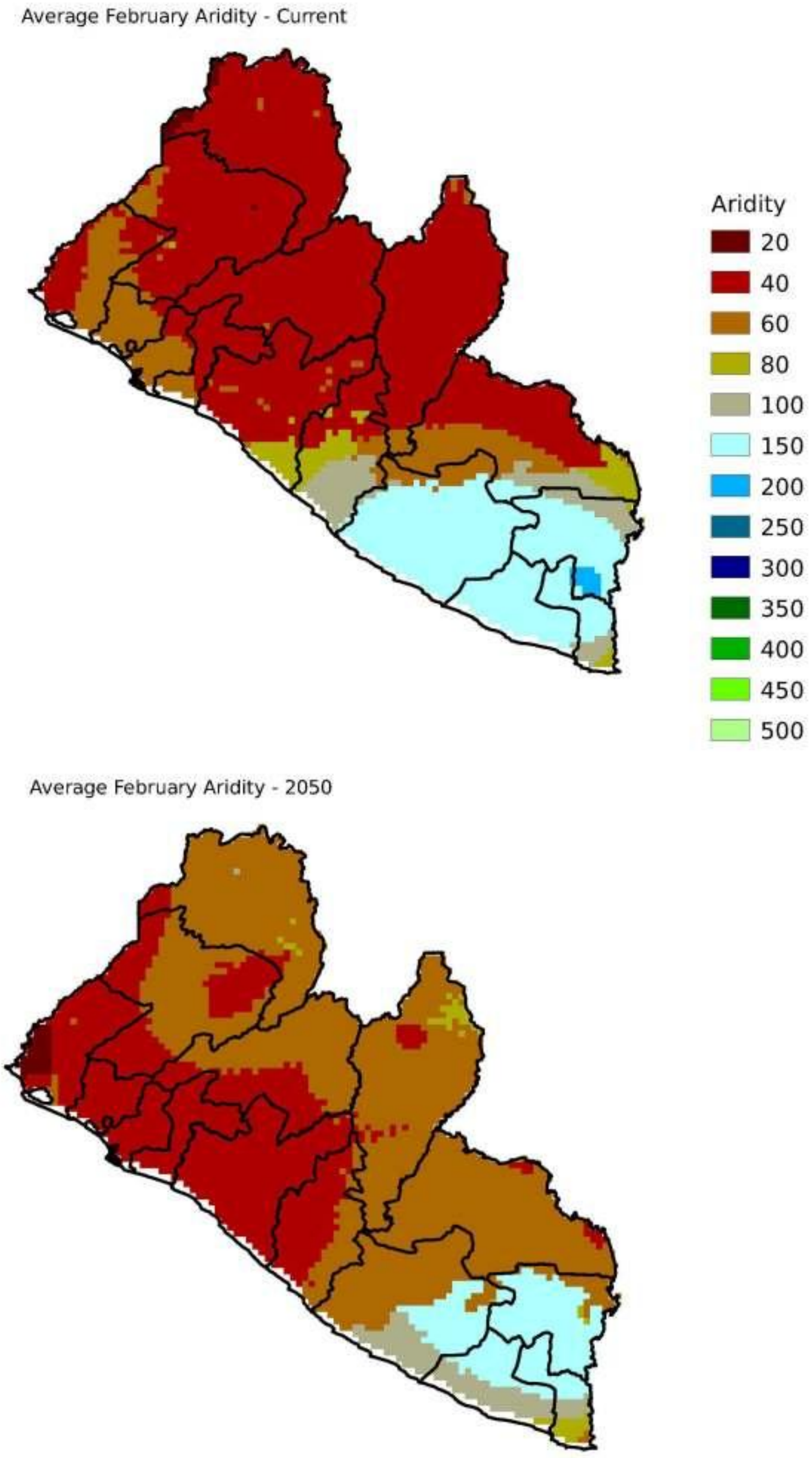


Figure 47 Average February aridity, current and 2050.

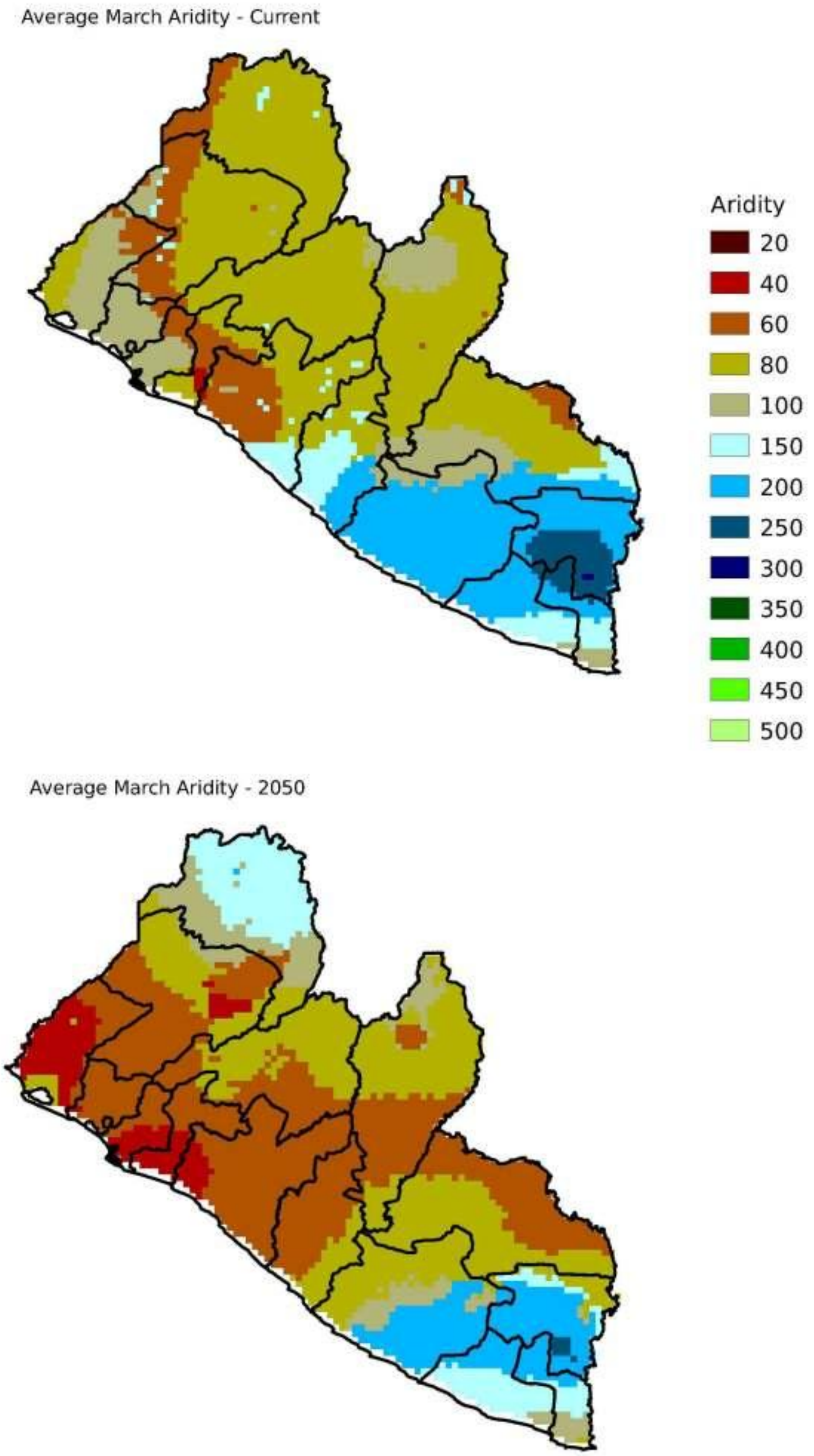


Figure 48 Average March aridity, current and 2050.

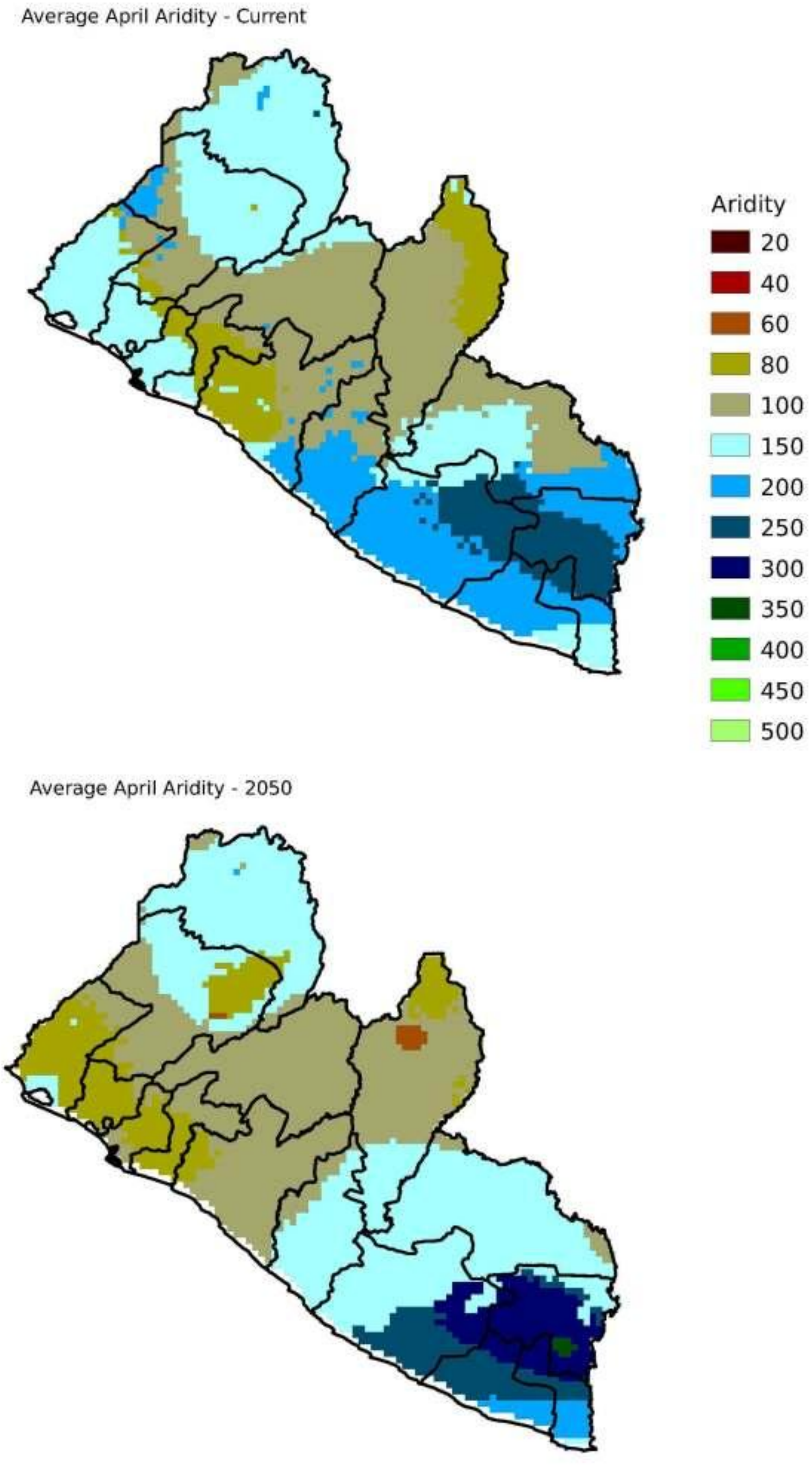


Figure 49 Average April aridity, current and 2050.

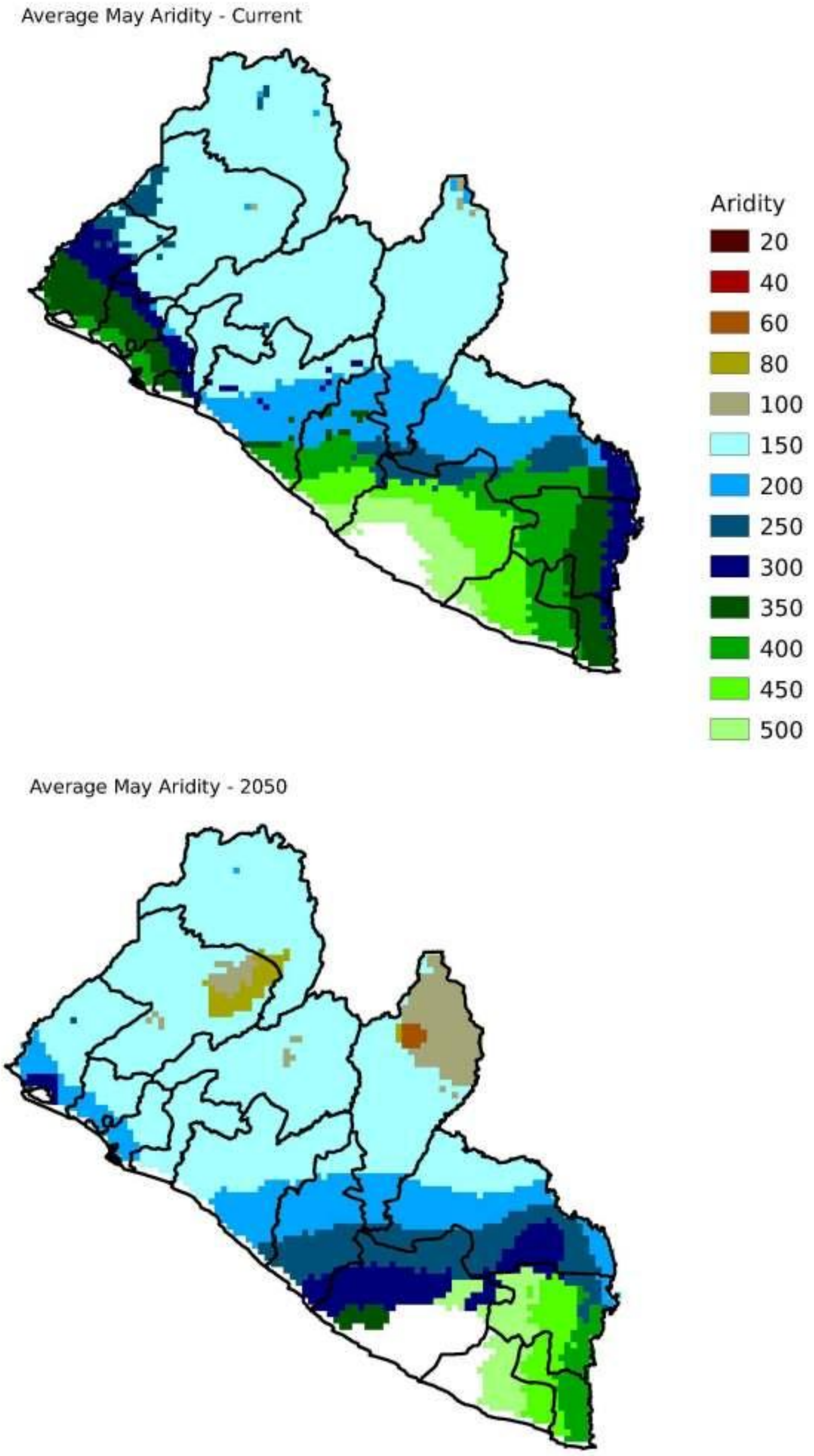


Figure 50 Average May aridity, current and 2050.

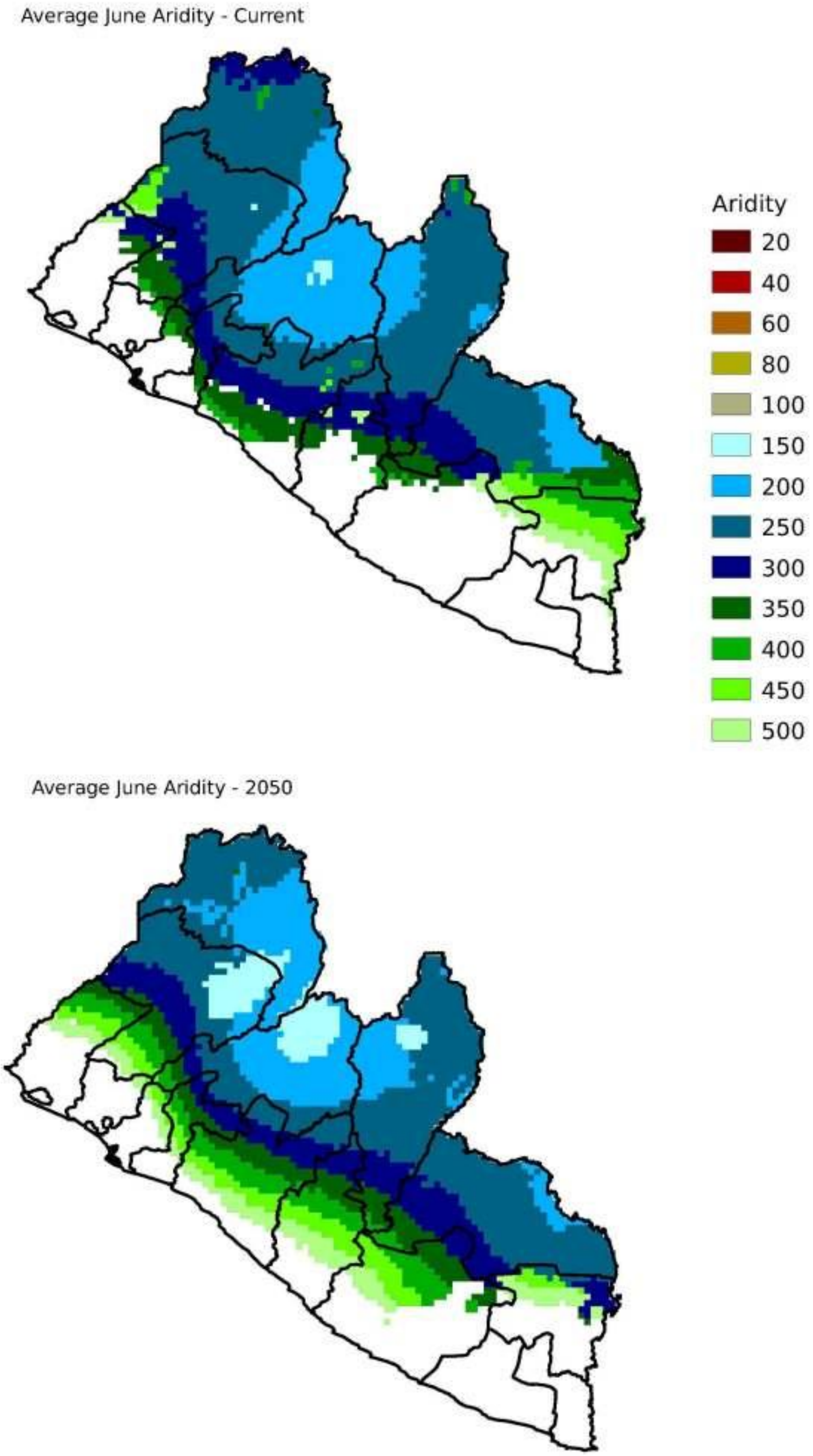


Figure 51 Avereage June aridity, current and 2050.

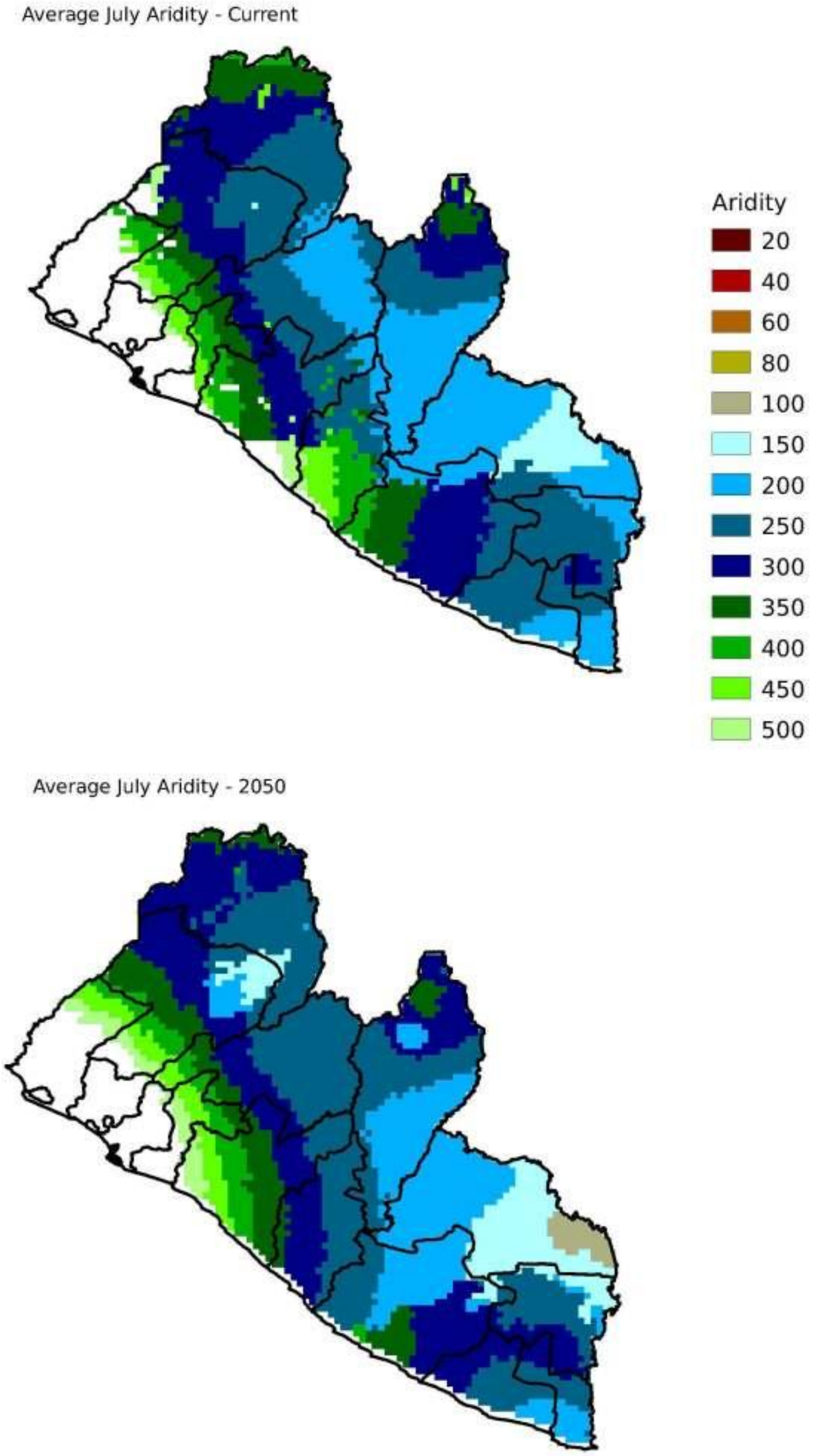


Figure 52 Average July aridity, current and 2050.

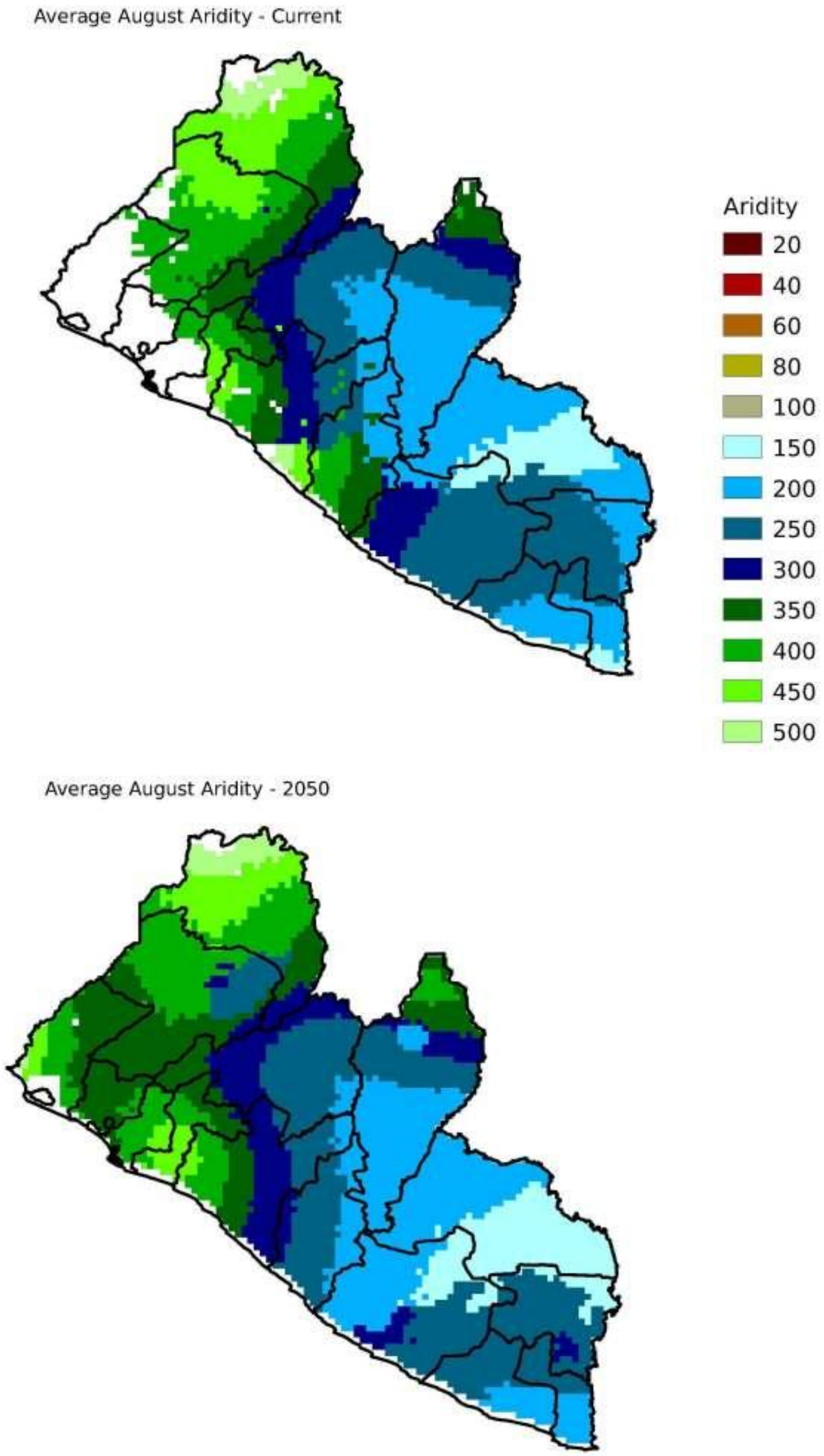


Figure 53 Average August aridity, current and 2050.

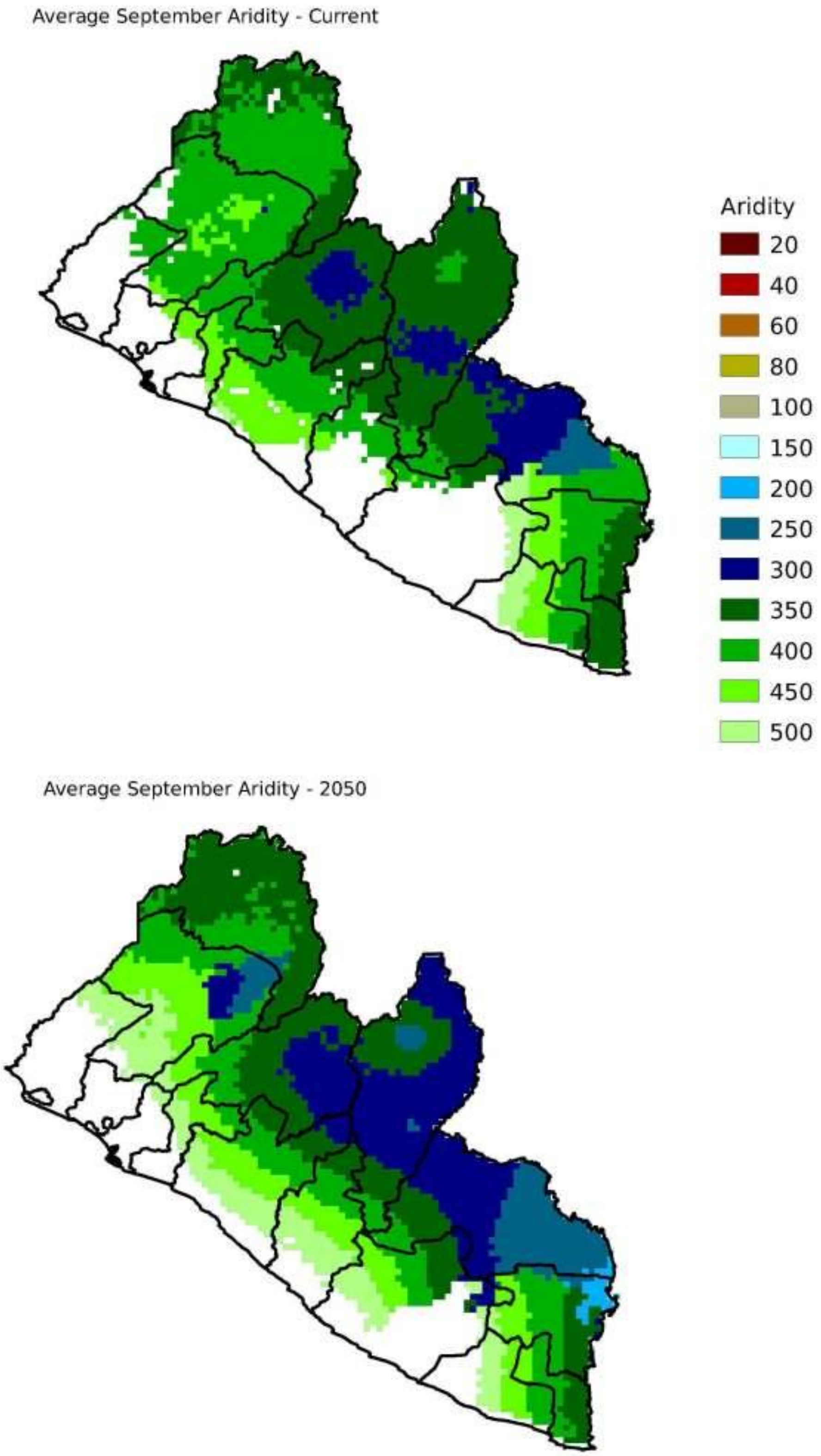


Figure 54 Average September aridity, current and 2050.

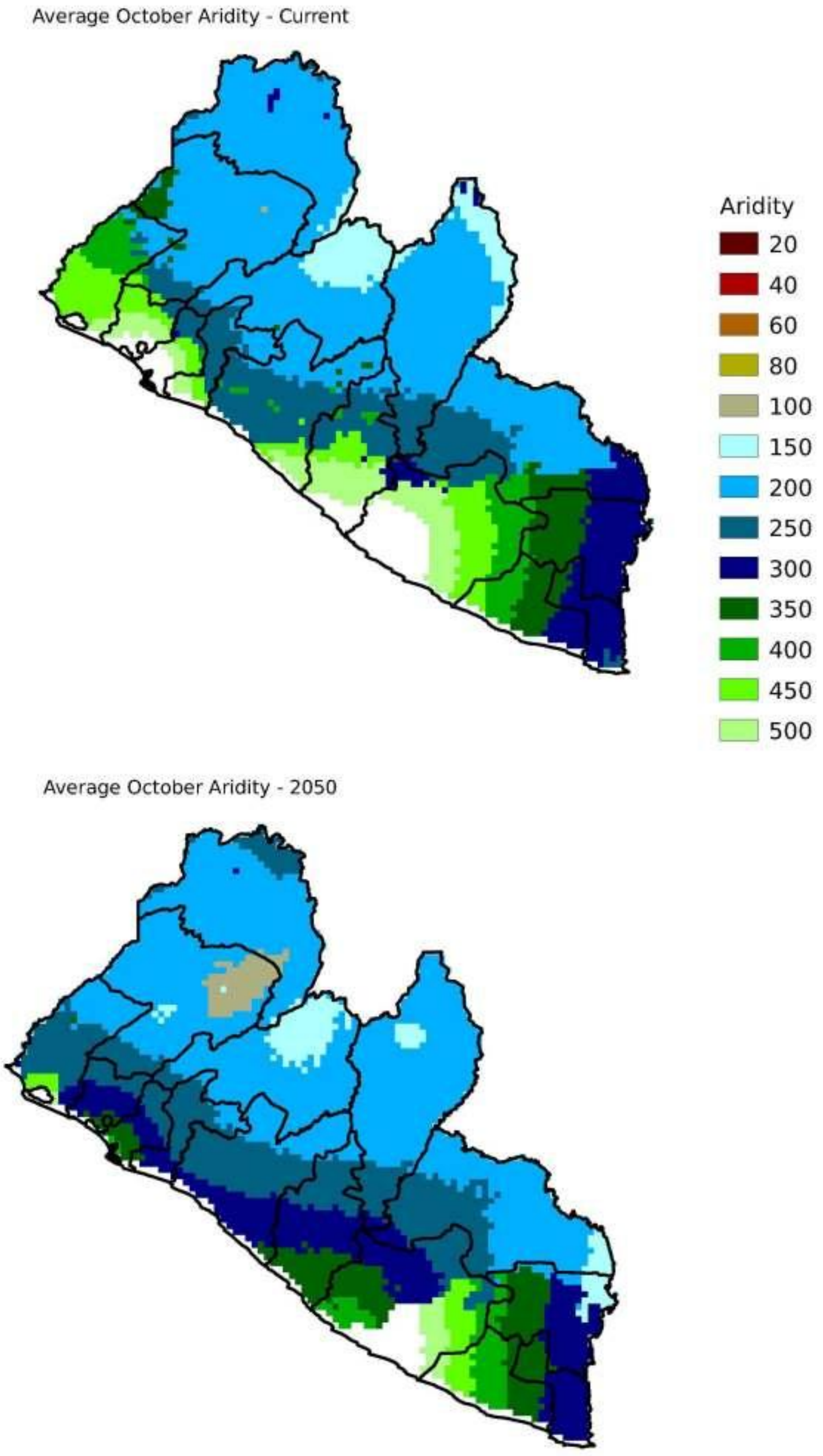


Figure 55 Average October aridity, current and 2050.

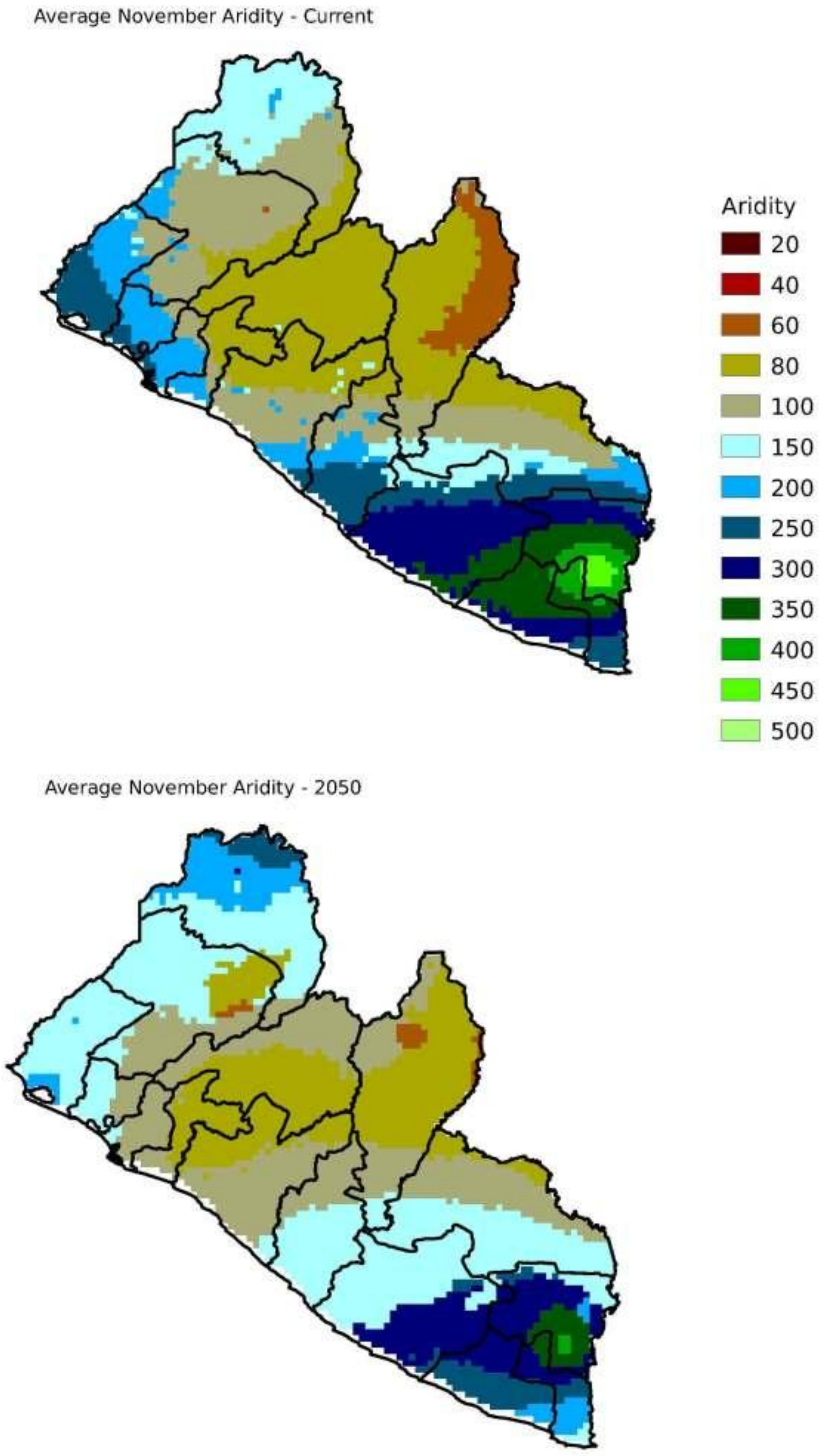
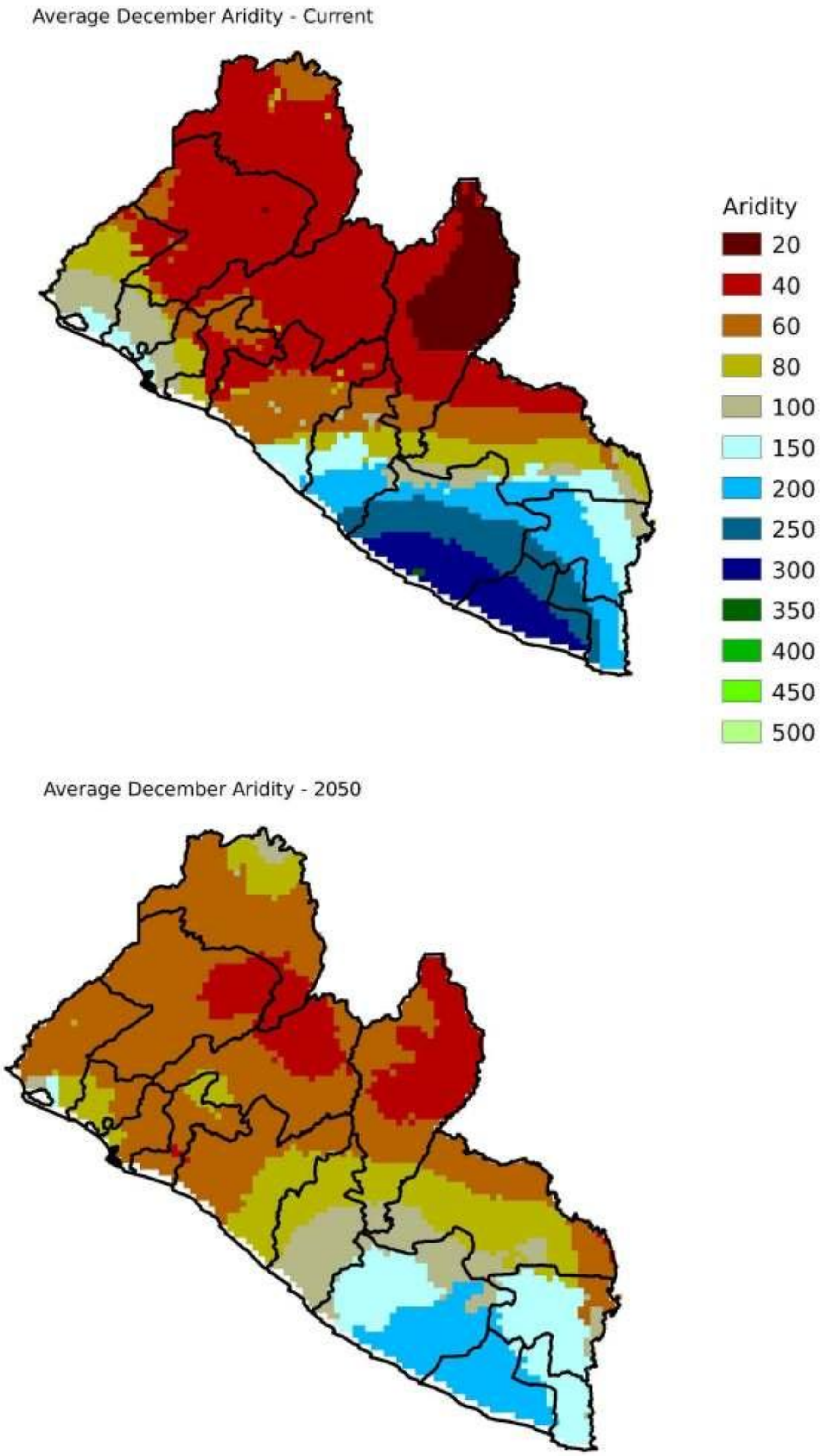


Figure 56 Average November aridity, current and 2050.



Average December Aridity - Current

Average December Aridity - 2050

Figure 57 Average December aridity, current and 2050.

POPULATION

Climate change will affect human populations physiologically by extremely high temperatures, increases in insect-borne diseases such as malaria, or water-borne illnesses. By the nature of statistical downscaling, we cannot project extreme temperature events. Overlaying the aridity change map on the social vulnerability map (Figure 58) indicates where the strongest climate change effects may be found. Clusters 1 and 4 were the most potentially vulnerable populations and people in Grand Cape Mount and Bomi Counties will experience the most climate change.

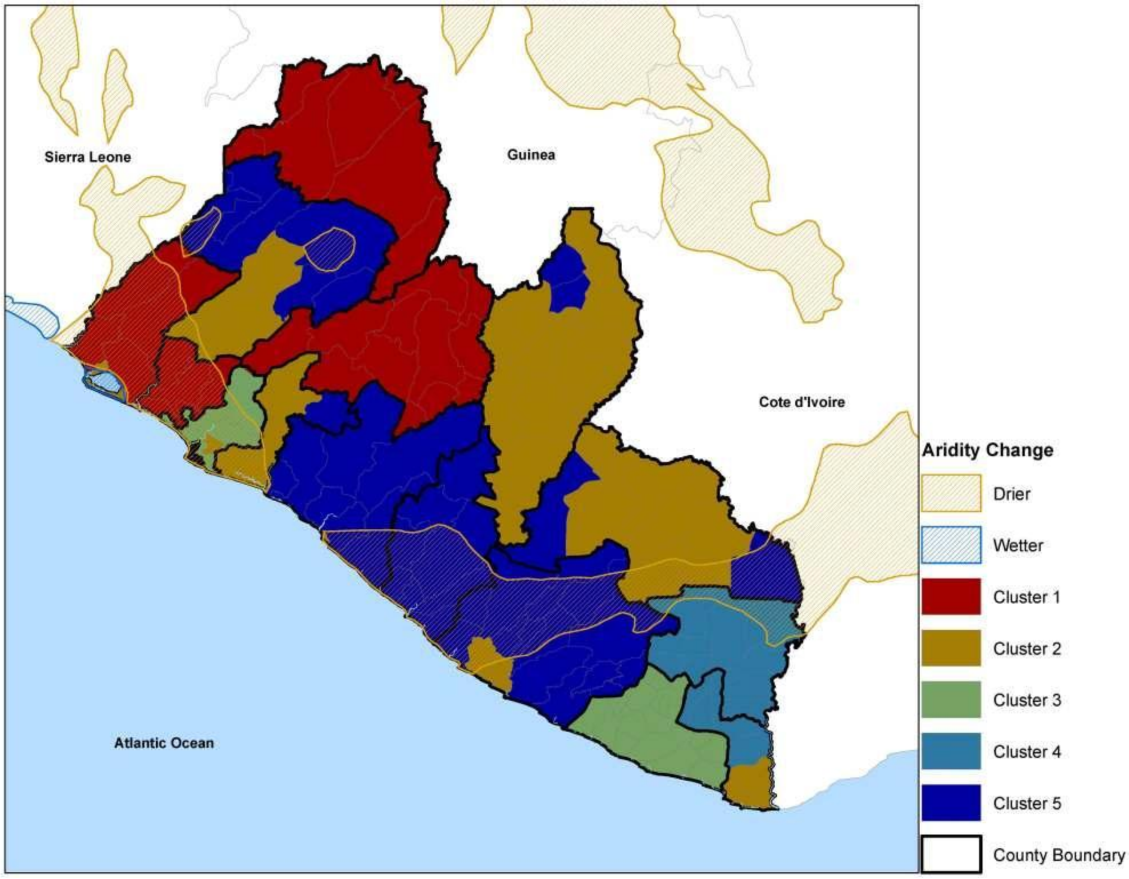


Figure 58 Overlaying the aridity change map on the vulnerability map.

AGRICULTURE

Climate change could impact agricultural production (commercial as well as subsistence) by less precipitation and higher temperatures on average, as well as altered patterns of the onset and duration of the rainy season. Because our data were too limited to model individual crops, we used the change in aridity as our indicator of climate change as well as the increase in average temperature of more than 2^{o}C.

Crops are vulnerable to climate variability as evidenced most obviously by lowered yields during drought periods and less dramatically by year-to-year variation in productivity. Variability can take many forms, such as for example, less total annual precipitation, delayed onset of the rainy period, higher temperature or sub-optimum moisture during critical growth stages (too moist during establishment might favor diseases such as damping off, too dry during grain-filling might lower yield). Changes in average climate values in regions currently at the limit for growing some crops could reduce yields to non-viable levels, for example causing a shift towards agropastoral systems. The complexity of crop growth requires climate data (short-term variability, frequency of extreme events) at spatial and temporal resolutions that are currently beyond the reach of climate change models (Challinor et al. 2007). Additionally, crop models generally are specified for monocropping and rarely consider intercropping. Improvements in both climate and crop models and the ability to model effects at scales from the farmer’s field to the region and nation will be critical to formulating adaptation options for agriculture and mainstreaming climate change into development programs (Challinor et al. 2007).

Several assessments have been made of the potential effect of climate change on crop yields in Africa (Challinor et al. 2007, 2009; Nelson et al. 2009). They are not readily compared because they use different global circulation models, IPCC emission scenarios, and crop models but they generally indicate negative effects for maize, rice, millet and cereals in general; effects range from +16% to -98% change in annual yields (Challinor et al., 2007). Linking five climate models and five emissions scenarios with a spatially explicit agro-ecosystem model and a global food system (trade) model provided an integrated system to examine not only climate change effects on agriculture but the effects of limited agronomic adaptation (Fischer et al. 2005). Effects of climate change on agricultural production were relatively minor globally but significant regionally. The interior counties of Bong, Lofa, and to a lesser extent Nimba were the primary agricultural areas before the conflict; these areas are the most likely to experience higher temperature maxima and altered rainfall patterns under the projected future climate.

Using our aridity index and overlaying the change map onto the main crop maps indicates the areas most likely to experience loss of food production (Figure 59 to Figure 62). Of the two main food crops, rice is the most vulnerable to climate change while cassava may benefit from climate change (Jarvis et al. 2012). Cassava is known to tolerate high temperatures and within-season drought as well as erratic rainfall patterns (Jarvis et al. 2012).

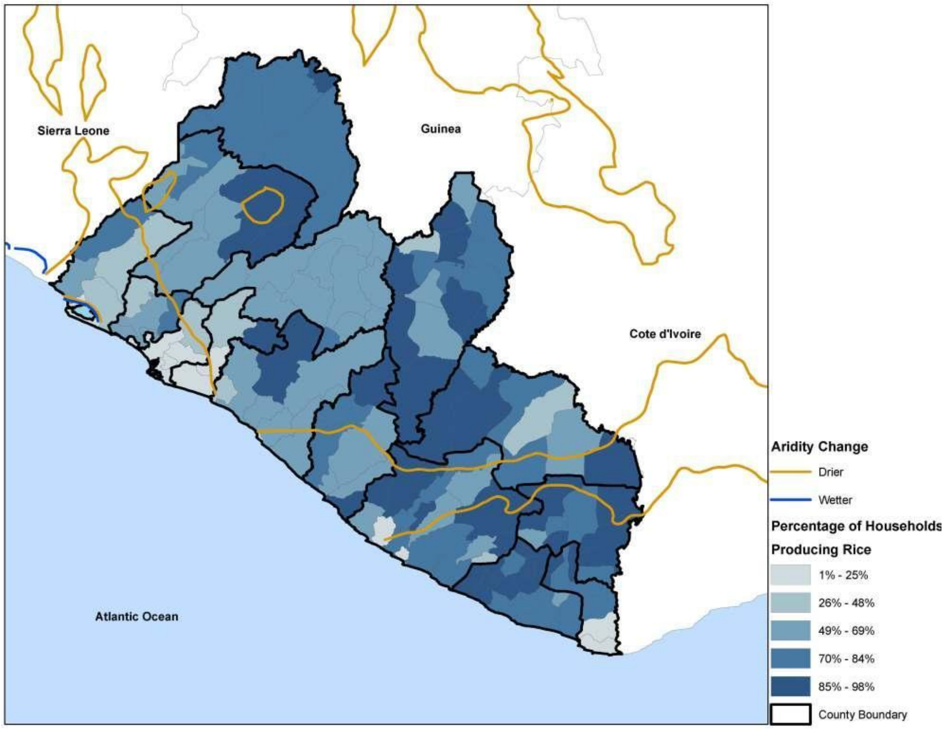


Figure 59 Change in aridity and households growing rice.

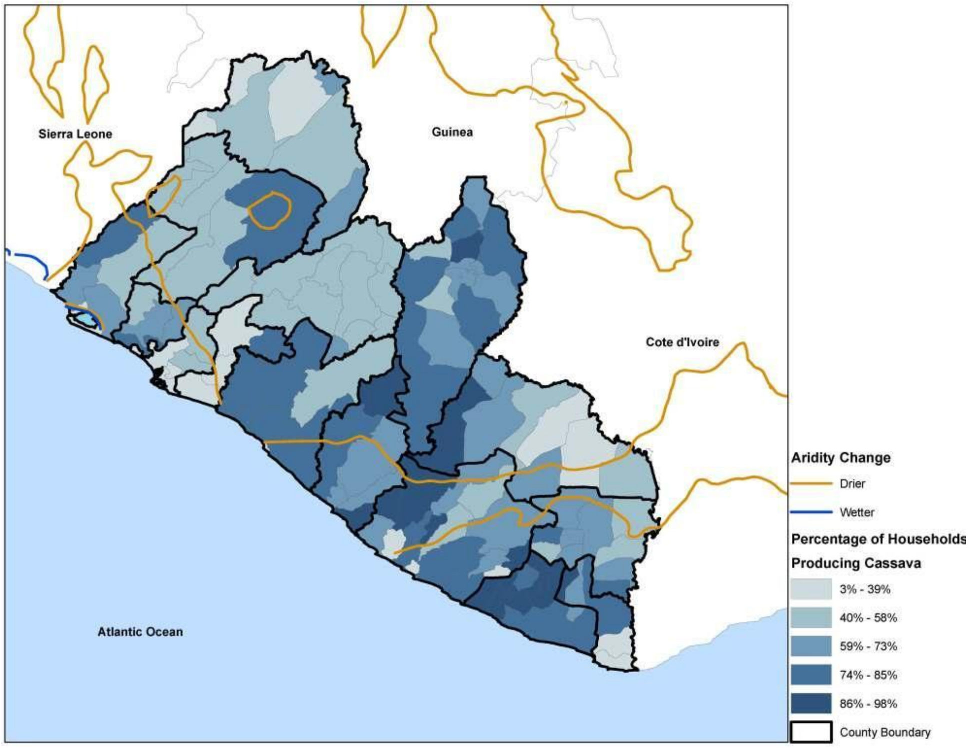


Figure 60 Aridity change and cassava producing households.

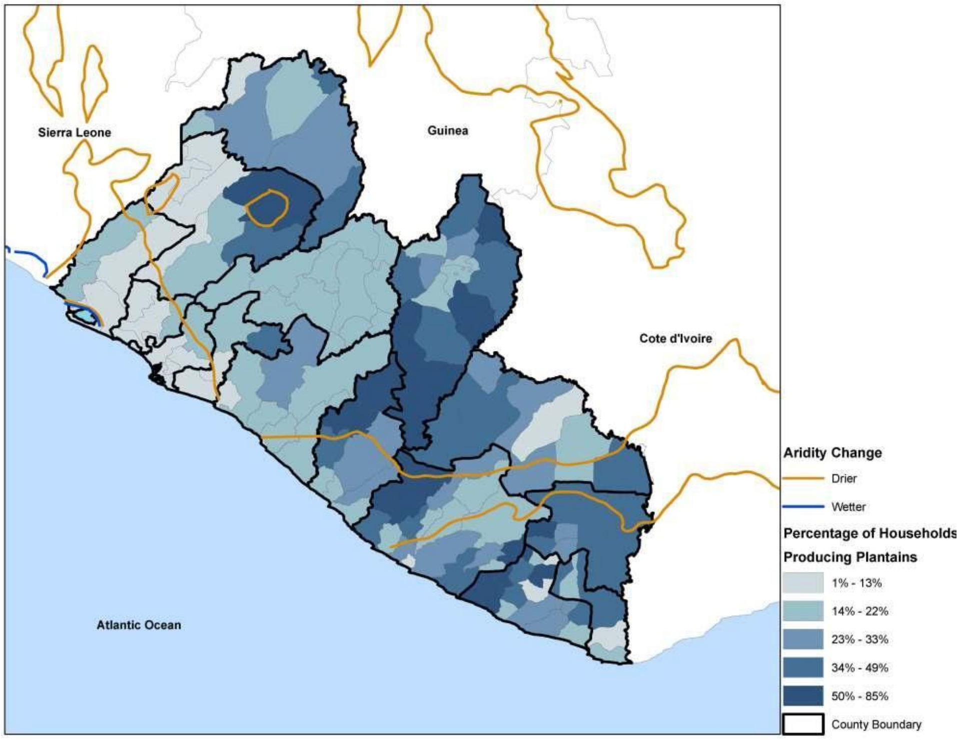


Figure 61 Aridity change and households growing plantains.

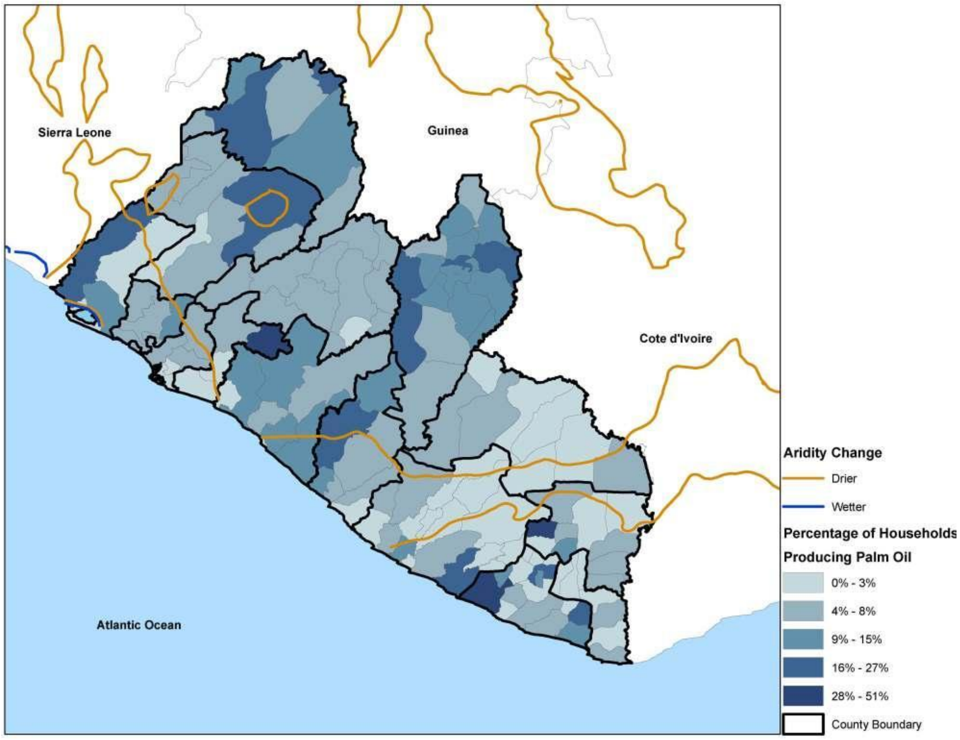


Figure 62 Aridity change and households producing palm oil.

FORESTS

The vulnerability of tropical rain forests to higher temperatures is hotly debated (Beaumont et al. 2007, 2011; Wright et al. 2009; Gonzalez et al. 2010; Iwamura et al. 2010). Thermal tolerances are not established for most species, although paleoecological evidence suggests selection for cold tolerance has been stronger than selection for heat tolerance (Colwell and Rangel 2010), implying that adaptation to higher temperatures could be low. Nevertheless, the preponderance of evidence is that tropical rain forest plant species are moisture limited although completely separating moisture and temperature sensitivity is not possible (Corlett 2011; Wright et al. 2009).

Even though projections of precipitation change are too model-dependent to say that climate change will impact tropical forests in Liberia directly, the change in aridity may indicate where forests are most at risk from the combined effects of human disturbance and climate change. Figure 63 overlays the change in aridity on the land use map, indicating the forest in eastern Liberia are the most likely area to be impacted by the “drier” climate in 2050.

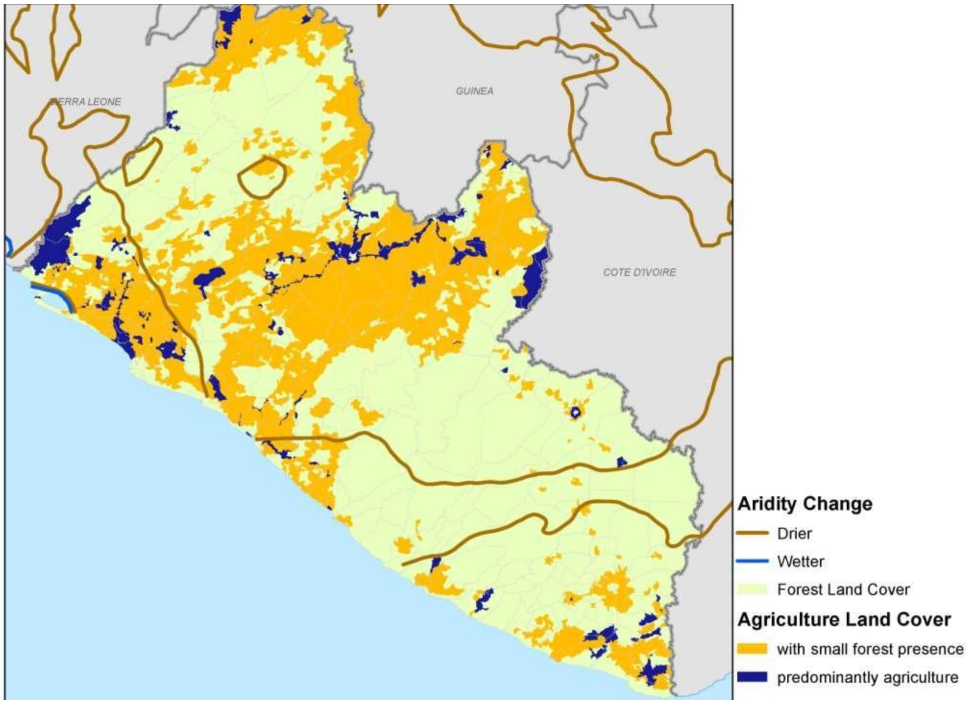


Figure 63 Aridity change and current land use.

More likely are the indirect effects from increased mining activity (see previous) and agricultural clearing. The farming areas in Grand cape Mount, Bomi and Montserrado Counties may experience declining productivity because of drier climate, resulting in expanded clearing of the small forest areas remaining. In River Cess, Sinoe and River Gee Counties, the currently intact forests may experience effects besides the loss from direct clearing. The combined effect of fragmentation from roads for development of the mining corridor (Figure 41) and clearing for small farmers will create a “savannization” effect. Opening up the forest canopy could lead to increased access to forests for pit-sawing and charcoal production, and a drying of the forest floor resulting in more wildfire ignitions from escaped agricultural burning, as seen throughout the Tropics (Myers 2006). In any event, wildfire is likely to become more important in all forested areas during dry periods as wildfire risk from climate change is projected to increase (Liu et al. 2010).

FISHERIES

Climate projections also indicated sea-surface temperatures will increase in Liberian waters with potentially negative implications for the dynamic and critical link between timing and intensity of the coastal upwelling and fishery productivity. Climate change impacts on the Liberian fishery will occur through a variety of direct and indirect pathways whose importance will vary depending on the type of ecosystem and fishery. Inland fisheries, particularly important for small-scale artisanal fishers in Liberia and an integral part of Liberian rural livelihood and food security systems could be severely impacted. Nearly the entire inland fishery lies in the Southern Upper Guinea Aquatic Ecoregion. The area is rich in aquatic insects, fish, freshwater decapods (e.g., seven of nine freshwater crab species are endemic), and frogs. About 20% of the 151 fishes from the ecoregion are endemic (Brown and Thieme 2005). Nevertheless, so little is known about the inland fishery in terms of rates of exploitation, diversity and status of fishes exploited, number of fishers, and state of the aquatic ecosystem that projections of climate change impacts on this important national resource are virtually impossible beyond broad generalizations. Precipitation and evapotranspiration changes, including an increase in extreme events (e.g., exacerbated floods, extreme drought), could affect inland waters causing changes in magnitude and timing of high and low river flows. These kinds of hydrological variability could adversely affect fish habitats, reproduction, growth, recruitment, and mortality.

Projections of change to the marine fishery are likewise premised primarily on generalization because of a lack of information on that resource. Severe climate change in conjunction with overfishing is projected to have significant impacts on the world’s marine fisheries with estimated losses of 50% of current gross revenues of about $US 80 billion/yr. This could result in billions of dollars of lost income by fishing households with serious economic, social, and food security ramifications (Sumaila and Cheung 2010). The most prominent effect of climate change on marine productivity and ultimately the fishery could be increased sea temperatures even though the primary proximate driver of productivity, the upwelling system, which is temperature dependent, is admittedly complex and certainly not totally understood (Wiafe et al., 2008) Sumaila and Cheung 2010). Changes in sea temperature and hence upwelling strength and timing could affect primary (phytoplankton) and secondary (zooplankton) production which in turn could dramatically increase or decrease the abundance of pelagic fishes and their predators. Other projected changes in marine systems involve acidification and expansion of hypoxic zones.

Climate change interaction with fisheries generally suggests that sea temperature increases may result in a shift in distribution (by depth or geographic location) or loss of fish and shellfish species, changes in ocean currents affecting primary and secondary productivity especially in fisheries dependent on upwelling zones, coral bleaching affecting reef fisheries, and disruption to fish reproductive patterns (timing, recruitment) and migratory routes (Koranteng, 1995; Mensah and Koranteng 1988; Wiafe et al. 2008). An increased frequency of extreme events could cause more frequent loss of fishing days and increased costs from loss of fishing gear (DAI 2008; Sumaila and Cheung 2010). Likewise fish distribution shifts could force fishers to "follow" again increasing costs in time, labor, equipment wear, and fuel.

Studies in the Gulf of Guinea adjacent to Ghana help inform the potential climate change situation for the marine fisheries of Liberia. Historical trend analyses of sea temperature in the Gulf of Guinea tend to show increasing trends in sea-surface temperatures for the period of record in the late 20th century. A detailed analysis (covering through 1992) showed: an overall increase in offshore sea-surface temperature from 1946-1990 with some evidence of short-lived, cyclical, decadal decreases; consistently increasing temperatures during the second warm (or low) season between 1975-1992; generally increasing sub-surface temperature (100 m depth) from 1969-1992; increasing sea-surface and sub-surface temperatures during the second warm or low season; generally reduced temperatures during the minor upwelling period (i.e., the upwelling was intensified); and slight increases in temperatures during the main warm or low season (i.e., intensification of warming) (Koranteng and McGlade 2001).

The period 1963-1992 could be divided into three distinct periods: an unsettled period from 1963-1974; a 'cold' period from 1975-1980; and a 'warm' period from 1981-1992. These periods apparently influenced the dynamics of the pelagic fishery resources with significant changes in the distribution and abundance of species coinciding with climatic periods (Koranteng and McGlade 2001). Another detailed analysis of seasonal trends over a 24-yr period (1968-1992) showed the annual cyclical nature of temperature and zooplankton productivity but also revealed gradual increases in sea-surface temperature for the major upwelling and second warm or low season (second thermocline) periods (Waife et al. 2008).

Importantly for climate change projections, these upward trends in sea-surface temperature were associated with significant decreasing trends in zooplankton biomass. Although other factors certainly influenced biomass of zooplankton (e.g., biomass of and predation by sardinella larvae), increased sea-surface temperatures accounted for >50% of the variation in zooplankton biomass (Waife et al. 2008). Importantly, future projections of sea-surface temperature from Global Climate Models estimate a 0.4, 1.4, and 2.7°C increases in sea-surface temperatures in coastal waters of the Gulf of Guinea in 2020, 2050, and 2080, respectively (Minia 2008).

The most abundant pelagic species in the upwelling region of the Gulf of Guinea (and off the Liberian coast) all are zooplankton dependent at early life stages and some are zooplankton dependent as adults (Mensah and Koranteng 1988; Koranteng 1995). Plankton abundance, providing forage for juvenile or adult fish, may be more important for sustaining stock biomass of some species than spawning success and larval survival (Binet 1995). Even if the declining zooplankton biomass is adequate for survival of the main fishery stocks (Mensah 1995), a month's lag exists between the peaks of sardinella larval abundance and total zooplankton biomass, suggesting, not surprisingly, a temporal matching between predators and peak larval food. As such, a potential exists for climate-change to cause a mismatch between larval pelagic fish abundance and their food which could compromise recruitment. Significant decline in zooplankton biomass occurred from the late 1960s to the early 1990s, a decline attributed to the trend in global warming (Wiafe et al. 2008). Although biological (top–down) control was also important, no long-term trend in the abundance of the predatory fish larvae was detected. The zooplankton time-series analysis at the biomass level combined with the knowledge of the biology and distribution of the dominant species during the major upwelling (i.e., a copepod, *Calanoides carinatus*) indicated the current trend in warming of the ocean, especially during the major upwelling, could shift zooplankton community abundance and structure and impact fishery resources (Wiafe et al. 2008).

Hence, climate change interaction with fisheries generally suggests that sea temperature increases may result in a shift in distribution (by depth or geographic location) or loss of fish and shellfish species, changes in ocean currents affecting primary and secondary productivity especially in fisheries dependent on upwelling zones, coral bleaching affecting reef fisheries, and disruption to fish reproductive patterns (timing, recruitment) and migratory routes. An increased frequency of extreme events, could cause more frequent loss of fishing days and increased costs from loss of fishing gear (DAI 2008, Sumaila and Cheung 2010). Likewise fish distribution shifts could force fishers to "follow" again increasing costs in time, labor, equipment wear, and fuel.

Global models of climate impacts on marine fisheries predict fishes will generally redistribute away from tropical countries toward cooler temperature countries (Cheung et al. 2009, 2010; Sumaila and Cheung 2010); thus tropical countries like Liberia may generally suffer the largest impacts. Under the SRES A1B scenario (i.e., a severe climate change impact), the west African coastal fishery maximum potential catch, including Liberia, is projected to decrease by as much as 31-50% by 2055 relative to the 2005 catch (Cheung et al., 2009, 2010). The model included 1,066 exploited species across a wide range of taxonomic groups (e.g., krill, shrimp, anchovy, tuna, sharks) making up about 70% of the total global reported fishery. Of those 79% showed a poleward range shift by 2050. Notably, the range shift for pelagic fishes was 600-km poleward and that for demersal fishes was 223-km poleward. Both these groups are mainstays of Liberia's fishery.

Given the unknown but suspected overexploited state of Liberia's marine fishery and the threat climate change poses for that resource, the GoL should be strongly encouraged to develop the capacity and infrastructure to scientifically monitor, regulate, and manage all sectors of the marine and freshwater fisheries for long-term sustainability. Local monitoring authorities should be strengthened and connected with local, regional, and national partners and counterparts. Many coastal residents are fisheries dependent, are vulnerable to disruptions in the resource, and have few employment alternatives. Tourism, while promising in the long term, lacks the infrastructure to provide substantial income. Investments in tourism infrastructure could provide coastal residents viable alternative livelihoods. Investments in education could broaden skill sets and widen employment opportunities for youth and young adults. (MPEA 2008)

Projections also indicate sea-surface temperatures will increase in Liberian waters with potential negative implications for the dynamic and critical link between timing and intensity of the coastal upwelling and fishery productivity. Associated in part with sea temperature increases is sea-level rise which is also projected to increase from 0.13-0.60 m by the late 21st century, depending on development scenarios modeled (Wiles 2005) although some sources project more than a 1 m rise (Jevrejeva et al. 2010). We examined coastal vulnerability to SLR by projecting increase sea level at 1 m intervals GoogleEarth with elevations based on satellite interferometry. In Figures 48-51, area that are at sea level are colored purple; areas that are 1 m or less above sea level are colored red. Higher elevation but potentially affected areas are colored orange (2 m ≤) or yellow (5 m ≤). High tides and storms could cause localized incursions of sea water into these areas. Alternatively, saltwater intrusion could cause areas not actually inundated to become more brackish, for example Lake Piso (Figure 64). The higher rainfall amounts predicted for coastal areas by 2050 (Figure 15) could result in more intense storms and localized flooding could change costal landforms and hydrologic connections such that areas now somewhat isolated become connected and allow seawater incursion into more areas.

COASTAL SYSTEMS

Communities worldwide in coastal areas will be impacted by projected rise in sea level caused by global warming; some West African countries already experience accelerating coastal erosion (e.g., Ghana, Liberia). The combined effects of on-going coastal erosion and climate change induced sea-level rise in Liberia are for the most part uncertain. Even so, obviously the highest risk will be for infrastructure and associated facilities located close to the coast or low-lying coastal lagoons or river estuaries. Historic shoreline rates of change in complex and dynamic large-scale coastal systems, like the currently eroding coastline of Liberia, cannot be assumed to continue into the future (Lakhan 2005). Recent acceleration in sea-level rise due to global warming is evident and at the upper boundary (worst-case) of initial projections (Rahmstorf 2007). With the expectation that sea-level rise will continue for centuries (IPCC 2007), future coastal recession can generally be expected to accelerate relative to the recent past (Addo et al. 2008).

Associated in part with sea temperature increases is sea-level rise (SLR) which is also projected to increase from 0.13-0.60 m by the late 21st century, depending on development scenarios modeled (Wiles 2005) although some sources project as much as a 1.6-m rise (Jevrejeva et al. 2010). We examined coastal vulnerability to SLR by projecting increase in sea level at 1-m intervals with elevations based on Google Earth, which uses digital elevation models from data collected by NASA's Shuttle Radar Topography Mission.

Liberia has a 565-km long coastline, and an estimated 95 km^2 of land along the coast of Liberia would be inundated if sea level rises 1 m (DAI 2008). Under a scenario of a 1-m rise in sea level about 50% (48 km^2) of the total land loss due to inundation will be the sheltered coast. For example, parts of the capital city of Monrovia, West Point, New Kru

Town, River Cess, Buchanan, and Robertsport will be lost because much of those areas are <1 m above mean sea level. Likewise seaward portions of the remaining mangrove wetlands will be lost. About $250 million worth of land and infrastructure will also be lost. Others using various global climate models project a sea-level rise in Liberia of 0.13-0.56 m by the 2090s relative to the sea level from 1980-1999 (McSweeney et al. 2010).

Sea-level rise could threaten ecologically, economically, and culturally important mangrove forests in Liberia. Mangroves grow along most of Liberia‘s coast line and estuaries, situated along the boundary between land and sea with water depth following tidal cycles. Because mangroves provide important habitat (e.g., spawning and nursery areas) for food fishes and shellfishes, loss of mangroves from sea-level rise could adversely impact artisanal lagoonal fisheries in Liberia. When mangrove forests are lost or degraded local fish catches generally decline (DAI 2008). Mangroves also provide many ecological goods and services for Liberia‘s coastal communities. Reduction in area of the mangrove wetlands could result in a loss of buffering capacity from violent storm surges; increased coastal erosion; exacerbated terrestrial flooding; reduced supplies of coastal timber, fuelwood, fish smoking wood, and artisanal medicinals; and affect ground water recharge and hence, freshwater supplies. The annual economic value of products and services that mangroves provide was estimated by UNEP to be between US$200,000 and US$900,000/ha. The situation in Liberia is further exacerbated because as sea levels rise, the mangroves in many areas cannot retreat further inland because they will be blocked by natural features and man-made obstructions (e.g., roads, settlements, agriculture).

The direct effects of a 1-m rise in mean sea level for the areas around Robertsport, for example, is relatively small (Figure 64) but extends the open water inland towards Lake Piso, the largest lake in Liberia (about 22 x 12 km). It is primarily brackish water, open coastal mangrove lagoon with a maximum depth of about 4-5 m (Gatter, 1997). Lake Piso and its surrounding wetlands are designated a wetland of international importance (Ramsar 2010) and also are a proposed Important Bird Area (IBA) in Liberia identified by the Society for the Conservation of Nature Liberia and BirdLife International because it supports a significant assemblage of biome-restricted (Guinea-Congo forest biome) bird species (Fishpool and Evans 2001). The wetland and surrounding savannah and forest also supports migrating birds, sea turtles, reptiles, mammals (e.g., West African manatees, primates), and fisheries.

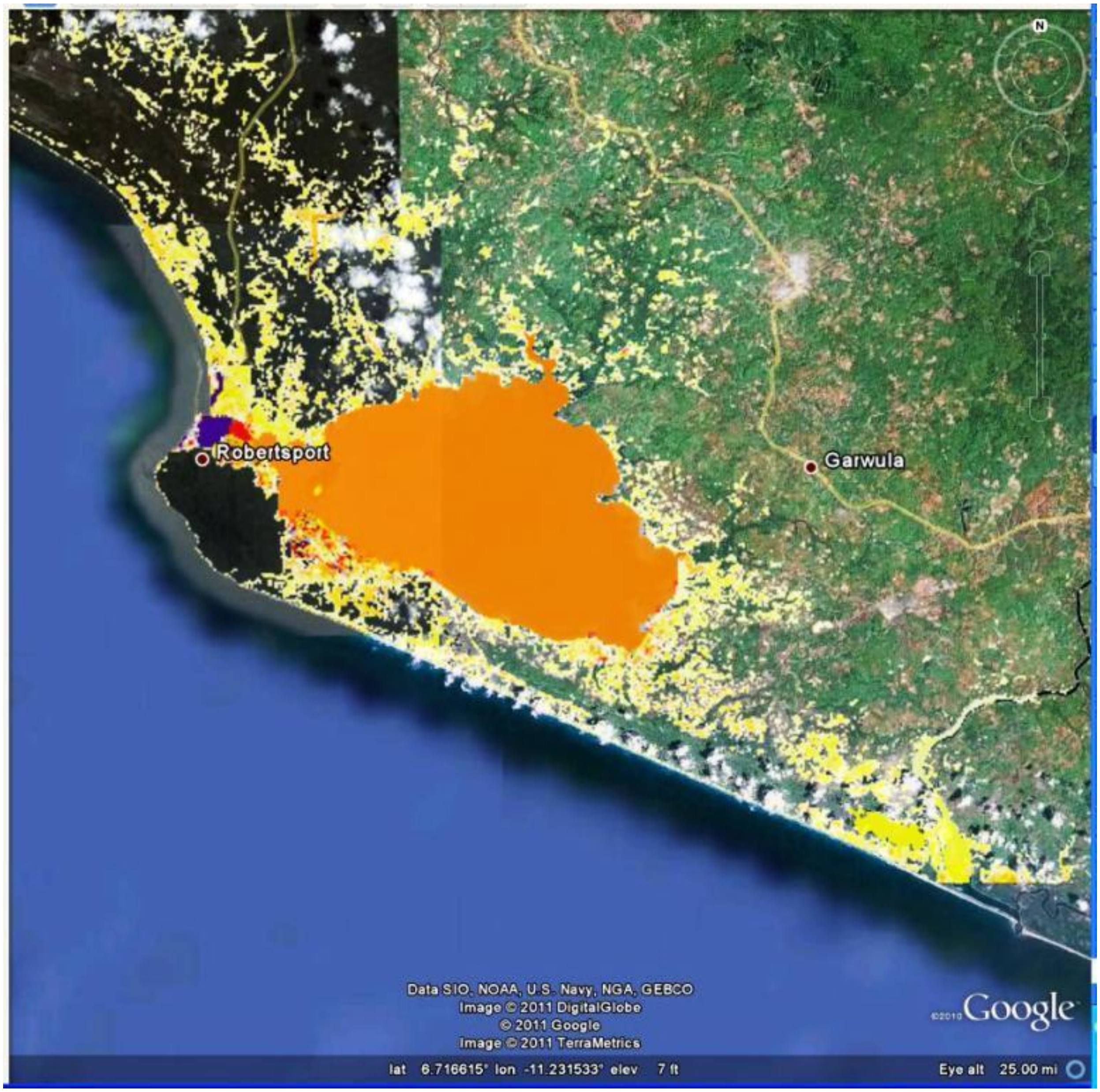


Figure 64 Projected sea-level rise along the coast near Robertsport; areas at sea level are colored purple; areas at 1 m or less above MSL are colored red. Higher elevations but potentially affected areas are colored orange (2≤) or yellow (5 m≤).

The satellite imagery suggests that the lake would be protected from a rise in mean sea level of 1 m but any change to the salinity conditions in the lake or the timing of the annual turnover could have significant impacts on the fisheries, mangroves, and wildlife. High tides and storms could cause localized incursions of sea water into the lake. Alternatively, saltwater intrusion could cause areas not actually inundated to become more brackish. The area currently receives about 3,000-3,500 mm of rainfall a year, near maximal for Liberia. The higher rainfall amounts predicted for coastal areas by 2050 could result in more intense storms and localized flooding could change coastal landforms and hydrologic connections such that areas now somewhat isolated become connected and allow seawater incursion into more areas.

Similar projections are shown for the coastal around Monrovia (Figure 65) and Buchanan (Figure 66). The map for Monrovia indicates many low-lying areas that are not directly connected to the ocean and thus are not directly vulnerable to sea level rise. Nevertheless, these are areas that are presently subject to flooding from heavy rains or likely to become more vulnerable as rainfall intensifies under projections from several climate models (Table 3).

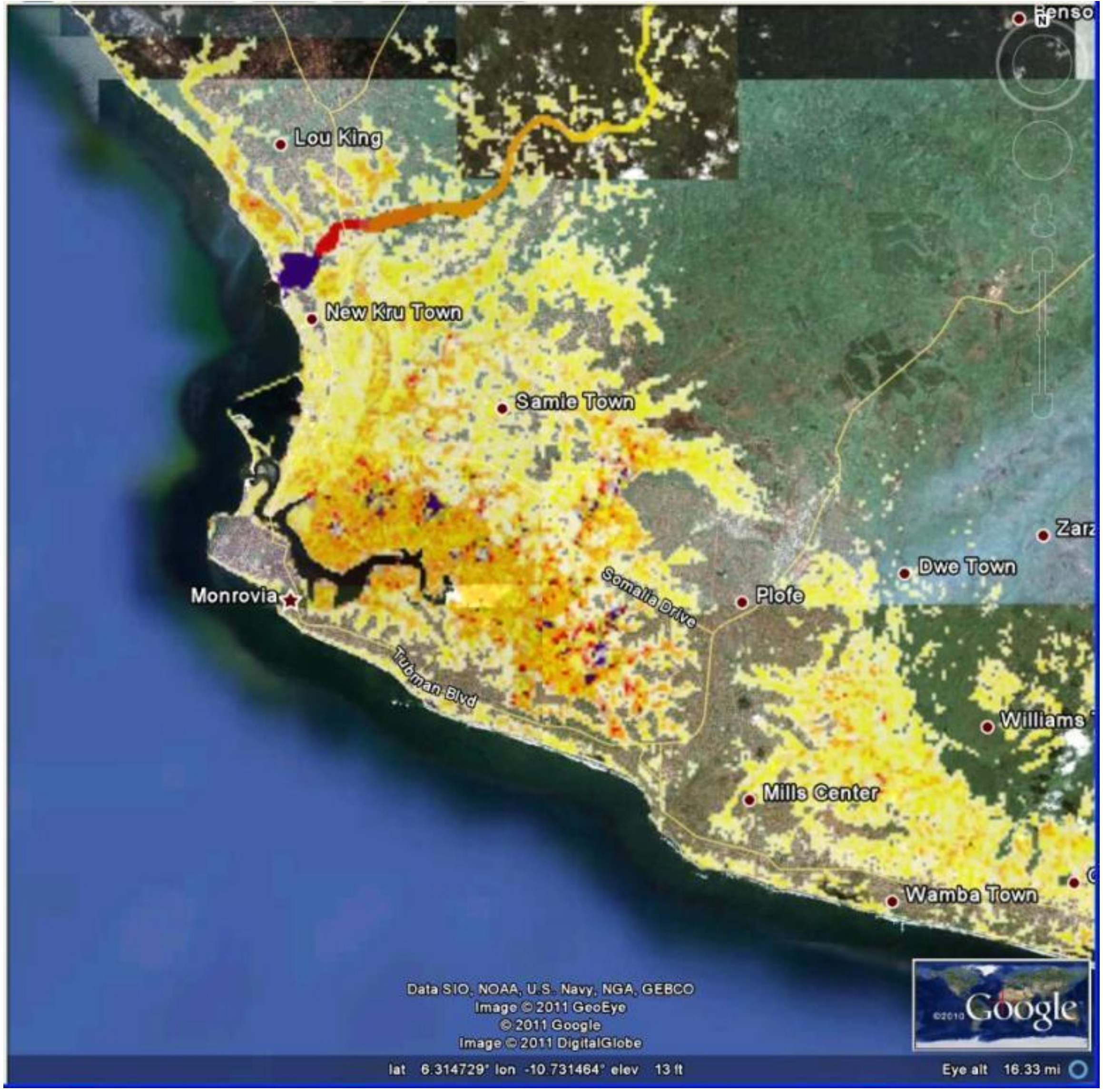


Figure 65 Areas along the coast near Monrovia vulnerable to sea level rise (colors as in Figure 64).

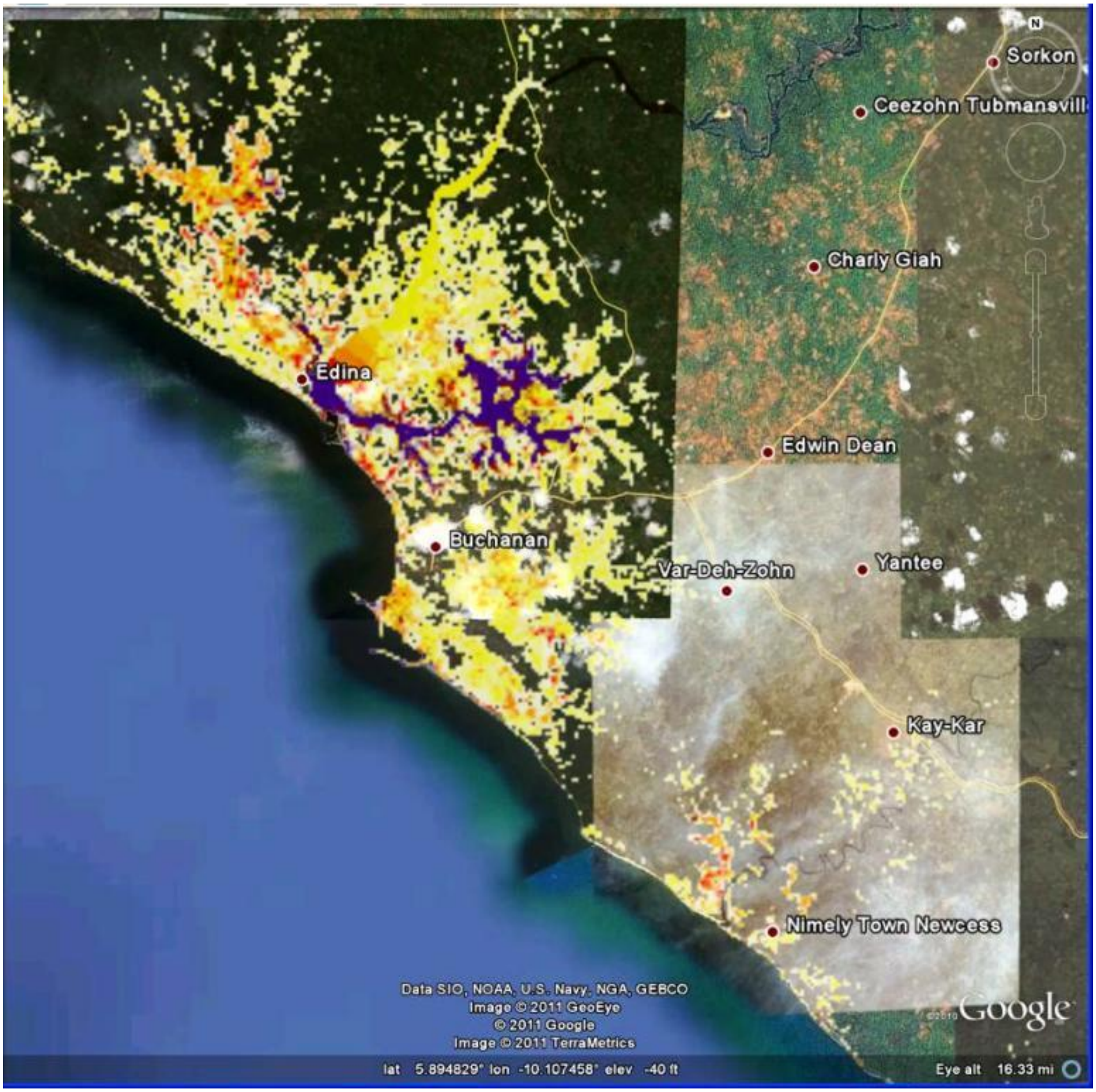


Figure 66 Areas along the coast near Buchanan vulnerable to sea level rise; colors as in Figure 64.

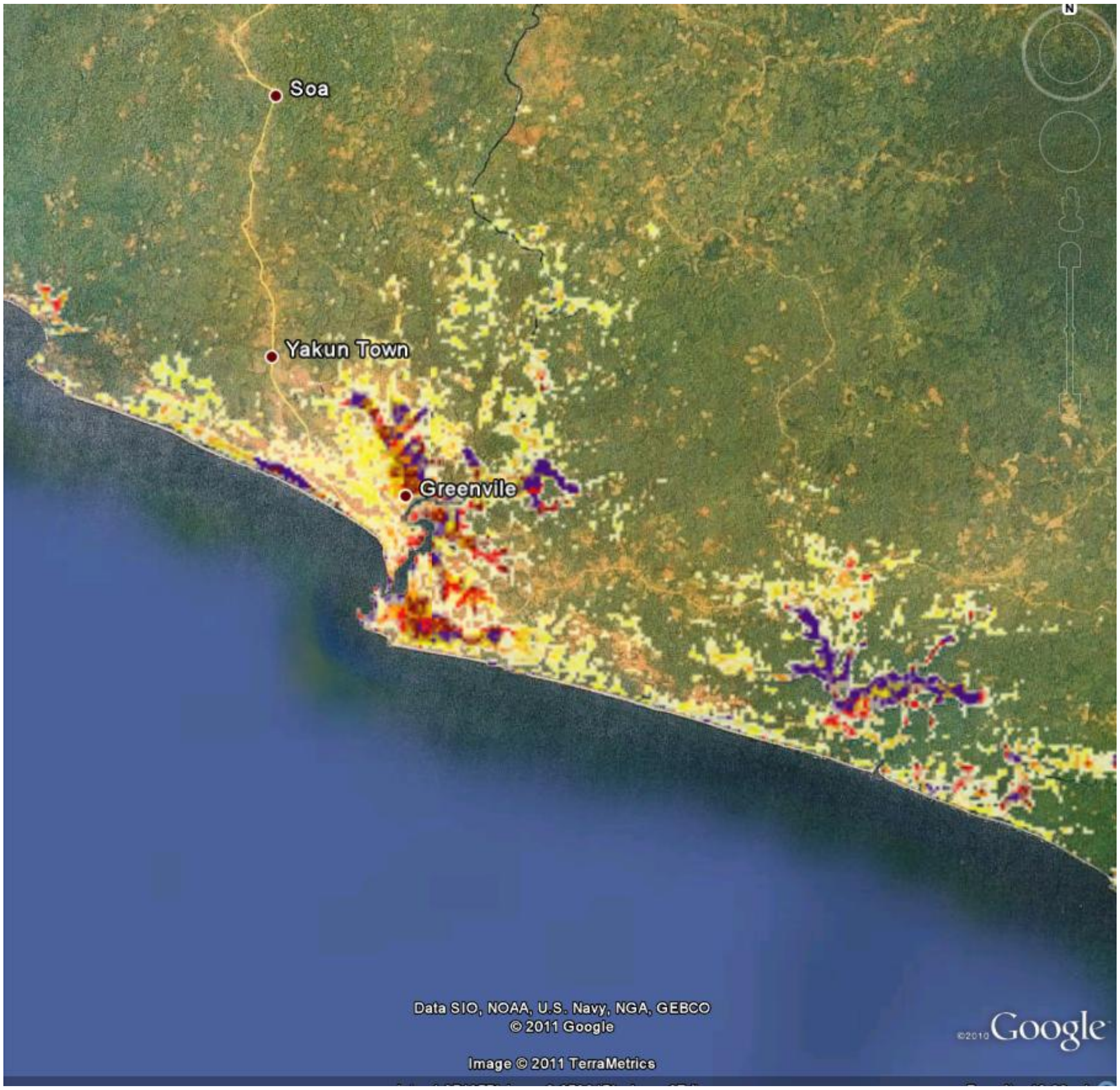


Figure 67 Areas along the coast around Greenville vulnerable to sea level rise; colors as in Figure 64.

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APPENDIX METHODS

CLIMATE MODELING

Although relatively easy and requiring minimal computer resources, the drawback of statistical down-scaling is that it produces a separate relationship for each variable of interest. Often only monthly means of temperature and rainfall are available. The most significant drawback is that statistical relationships based on current conditions are assumed to continue to hold in the future conditions. Statistical downscaling works best where an extensive network of weather stations exists providing the data to build these relationships. In Liberia, as in much of Africa, this is not the case. Thus broad spatial patterns are reproduced in the down-scaled data even though there may be significant topographic features at the finer that would modify climate.

Dynamic down-scaling, a focus of our continuing work in Liberia, is one such improvement that uses higher resolution regional climate models to add underlying regional scale details to coarse global model output. Spatial variations are handled by physics rather than statistical interpolation between data points. These models can be nested to yield even higher resolution projections over smaller areas. The greatest limitations of dynamic down-scaling are the computer resources needed and skilled meteorological modelers. The trade-off is in better control of variables and time resolution (output is not restricted to monthly temperature and precipitation means) and variables are consistent; that is to say, relationships among variable are physically-based. Projections from dynamically down-scaled climate models are adaptable to a wider range of questions and closer to the spatial and temporal scales needed for making development and resource management decisions. For example, output can be manipulated to provide the frequency of precipitation events of a given magnitude, likelihood of extreme events such as growing season drought, and changes in the timing of the probable start of the rainy season or the mid-drys.

Even with such improvements, uncertainty remains because these dynamically down-scaled regional climate models begin with the boundary conditions set by the GCMs. As noted, GCMs inadequately model the interaction of the ITCZ and the West African Monsoon (Annamalai et al. 2007). Improvements are needed to provide reliable precipitation projections for the rainforest zone in Africa so that the possible effects of climate change on agriculture and natural systems can be understood.

STATISTICAL DOWNSCALING METHODS

Model Description

The Regional Climate Model version 4 (RegCM4) is a hydrostatic, compressible, sigma-p vertical coordinate model run on an Arakawa B-grid in which wind and thermo-dynamical variables are horizontally staggered (Giorgi et al. 2012). The 2 fastest gravity waves are removed from the model solution and integrated separately, which allows the remainder of the model solution to have smaller time steps. RegCM4 has the same physics package as the hydrostatic version of the PSU/NCAR mesoscale model (MM5, Grell et al. 1994). Improvements in this version of RegCM includes new planetary boundary, air-sea flux, and land surface schemes. There is also an option to mix the Grell and MIT convection schemes to improve the representation of precipitation over land and water.

Model Aspects

Table 7 Model Options Used for the REGCM4 Simulation.

Dynamics	Hydrostatic, ϭ-vertical coordinate (Giorgi et al. 1993)
Radiative transfer	Modified CCM3 (Kiehl et al. 1996)
Cumulus convection	Grell (Grell 1993)
Resolved scale precipitation	SUBEX (Pal et al. 2000)
Land surface	BATS (Dickinson et al. 1993)

Data Description

The analysis herein was produced using the ERA-Interim (ERA) reanalysis data as the boundary conditions for the current climate state and the ECHAM5 A1B scenario projection data forcing for the future analysis. The ERA reanalysis is produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) and is available from Jan 1, 1979 to present. ECHAM5 is the 5th generation of the ECHAM general circulation model developed at the Max Planck Institute for Meteorology in Hamburg evolving originally from the spectral weather prediction model of the ECMWF. The model is used to produce future climate projections under the A1B scenario as defined by the Intergovernmental Panel on Climate Change (IPCC). The ECHAM5 projection dataset has been shown to have a slight warm bias (Ozturt et al. 2012).

Methodology

We analyzed two 10 year time frames; a current and a future climate simulation using the RegCM4 regional climate model. The time period designated as current is 1998-2007 and from 2021-2030 for the future climate state. A start date of 1998 for the current climate analysis period is desired, so the spatial pattern of the modeled precipitation fields could be compared to observations, mainly the Tropical Rainfall Measurement Mission

(TRMM) and Modern Era-Retrospective Analysis for Research and Application (MERRA) data sets. From the two simulations we determined monthly maximum and minimum temperature as well as monthly total precipitation climatology within the domain centered on Liberia. From the model generated climatology information an aridity index was developed. The selected variables were analyzed and compared to discern spatial differences between the two analysis periods. This manner of evaluation is one possible scenario of how the climate of Liberia will change in the future when compared to an idealization of the current climate state.

Model Comparison To Observations

Climate change has the ability to impact many fundamental aspects of day to day activities. With this in mind, it is highly important to understand and project the nature and magnitude of the changes in the climate. To accomplish this task with any sense of confidence, the model representation of the present day climate (1998-2007) was validated by comparing model output with observational data (TRMM, MERRA). The temperature and precipitation regimes produced by the model simulations were in good agreement with the characteristics of the observed temperature and precipitation fields (see figures below), although the RegCM4 model has been shown to overestimate precipitation over the West African monsoon region.

Images

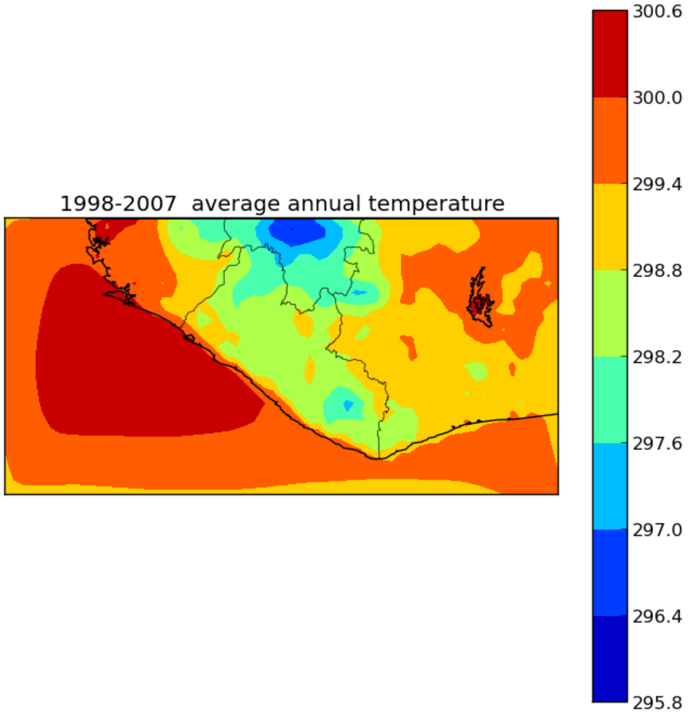

Figure 68 RegCM4 1998-2007 annual average temperature (K)

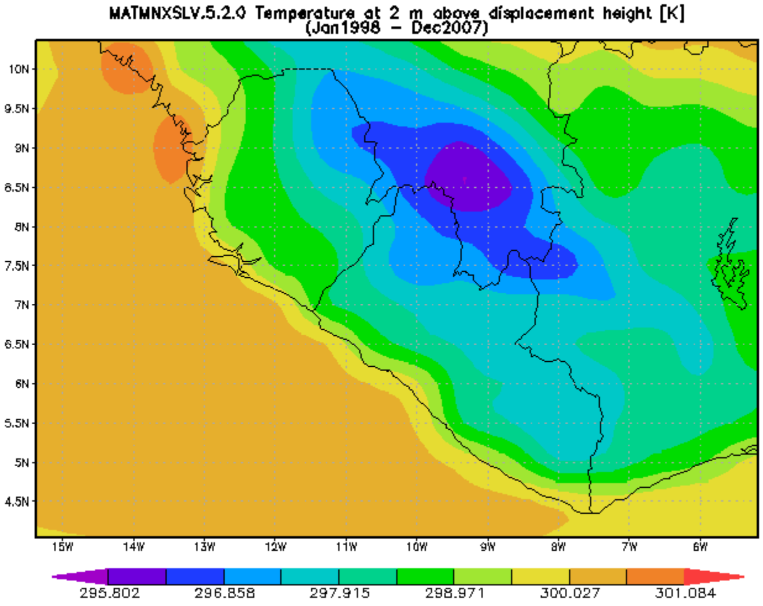

Figure 69 FMERRA temperature at 2m (K)

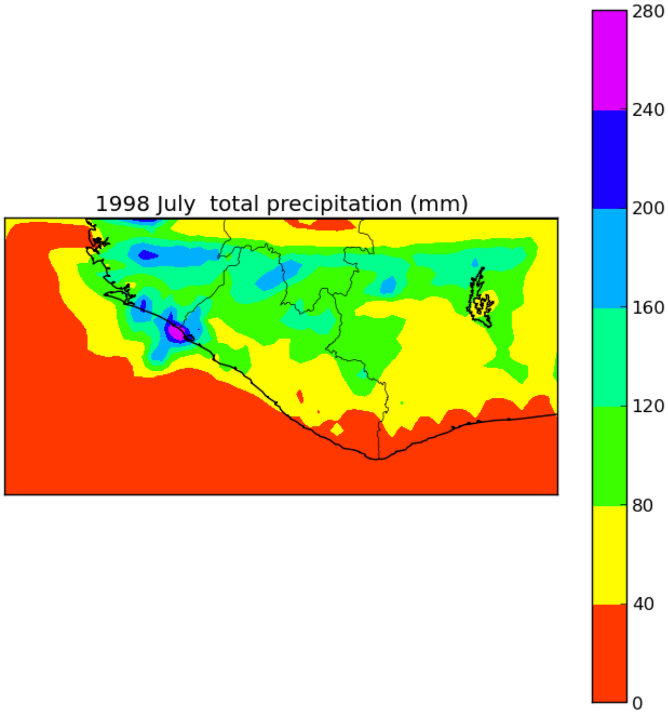

Figure 70 RegCM4 July 1998 total precipitation (mm)

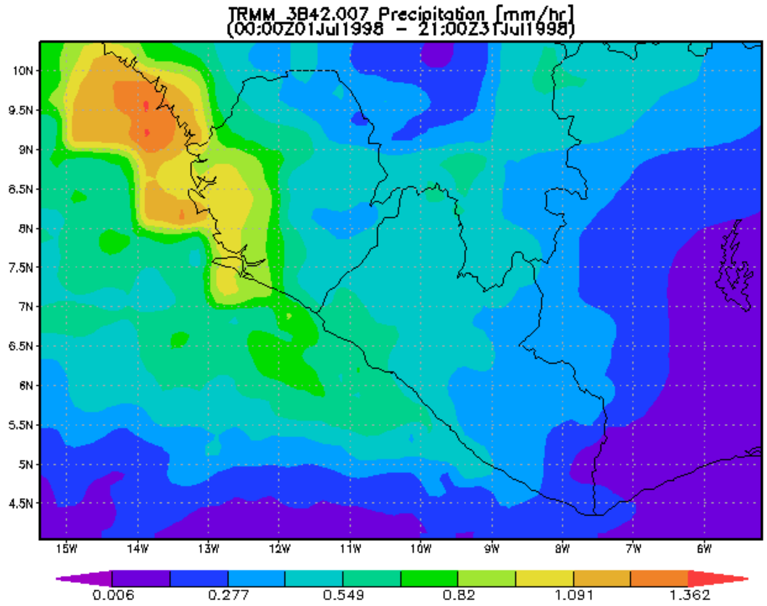

Figure 71 TRMM July total precipitation (mm/hr)

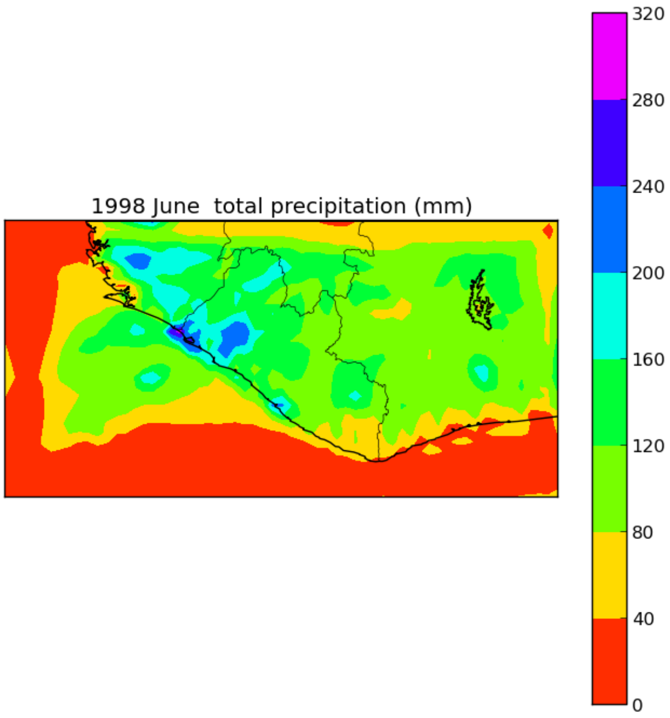

Figure 72 RegCM4 June 1998 total precipitation (mm)

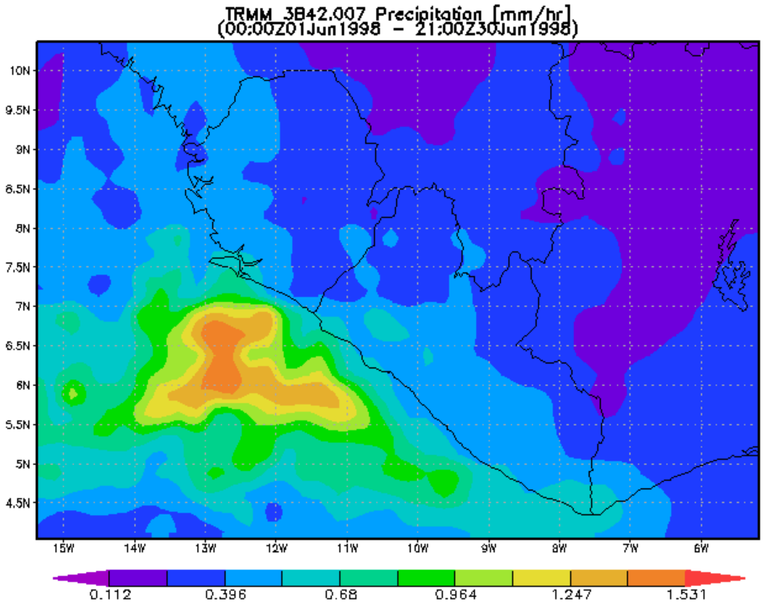

Figure 73 TRMM June 1998 total precipitation (mm/hr)

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SOCIAL VULNERABILITY PROCESSING FOR LIBERIA

Our analysis of social vulnerability focused on 18 social attributes (12 at the district level from census data including: Displacement, Distance to Drinking Water, Distance to Medical, Illiterate, No Fish, No Furniture, No Livestock, No Mattress, No Poultry, Substandard Housing, Unimproved Drinking Source, and Unimproved Sanitation; and 6 specified only at the county level: Dependent Population, Disabled Population, Percent Undernourished, Prevalence Stunted Children, Without Access to Free Health Care/Drugs and Access to Land). The first step in the analysis was a principle component analysis based on the correlation matrix to determine to what degree the dimensionality of the dataset could be reduced by taking advantage of the likely inter-relationship among the various social traits. The scree plot from the PCA (Figure 74) revealed that the social traits do show some inter-relations, but this relatedness is spread across more than just a few principal components. Kaiser's rule dictates that only those components accounting for more than the average amount of the total variance be retained in PCA which in the case would dictate 6 components be retained (Wilks, 1995); however, since the scree plot is not showing a natural break at this point we retained 7 principal components which accounted for 77% of the variance expressed by the original 18 social traits.

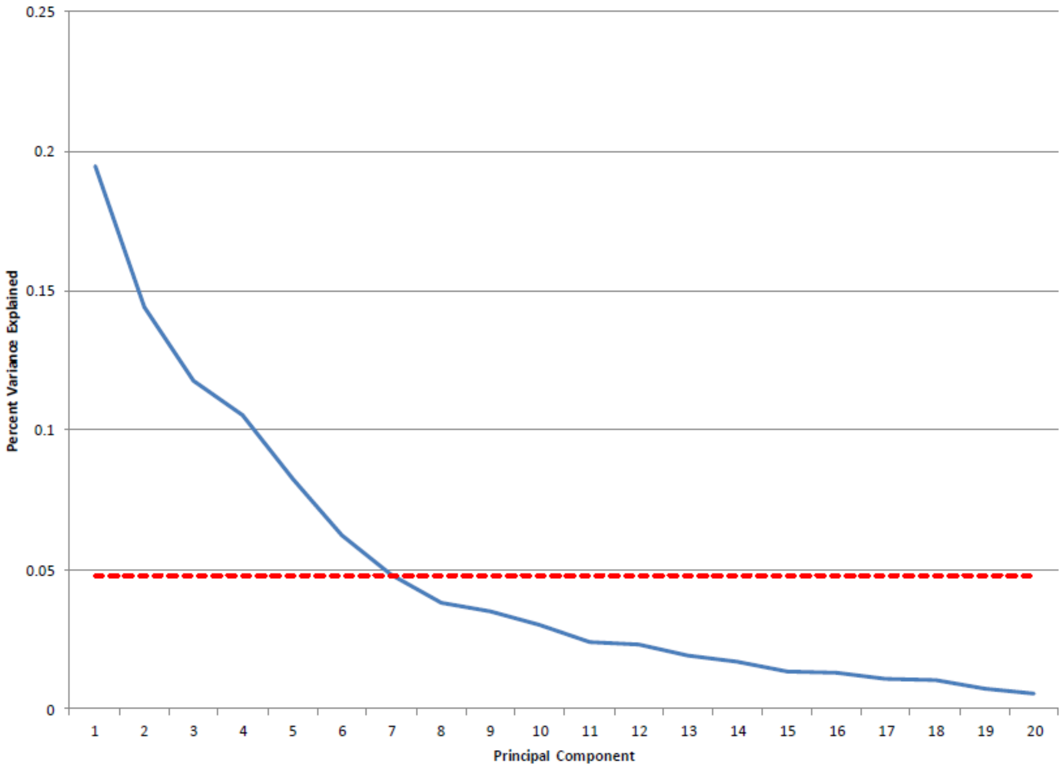

Figure 74 Scree plot of the principal components analysis of social factors.

Using the knowledge that our dataset could be represented by 7 principal components, a factor analysis was conducted. The p-value on the factor analysis assuming 7 factors was 0.186 which indicates that 7 factors are sufficient to capture the dimensionality of the social dataset. The factor loadings for the various social traits reveal which traits contributed most strongly to each factor (Table 8). Factor 1 is most strongly influenced by Unimproved Drinking Sources, Unimproved Sanitation, Distance to Medical Care, Distance to Drinking Water and the percent of population that is Illiterate. Factor 2 is driven by availability of protein sources (No Livestock, No Poultry, and No Fish); however, livestock is not purely a protein source as it is also an indicator of affluence. Factor 3 reflects the influence of the percent of population that is Undernourished which is a county level variable and the Prevalence of Stunted Children, another county level variable. Factor 4 is most influenced by the percentage of the population that is Displaced and the lack of a Mattress. Factor 5 comprises the Disabled and Dependent portions of the population. Factor 6 couples the access to free medical care/drugs and the access to land (both county level variables). Factor 7 is most influenced by the lack of furniture and lack of a mattress. One trait did not show up as dominant contributors to any of the factors, Substandard Housing.

The first 5 factors account for the majority of the variance explained by the seven factors and are the most easily interpreted. Factor 1 can be thought of as a “water quality” factor due to the strong influence of the Unimproved Drinking Sources and Unimproved Sanitation traits. Factor 2 reflects “food quality” as it is dominated by the three possible protein sources. Factor 3 reflects “food quantity” as its strongest traits are percent of population under-nourished and prevalence of stunted children. Factor 4 reflects the added stress on local resources by “displaced populations”. Factor 5 groups disabled and dependent populations and reflects a stress on local resources that differs from that of Factor 4.

Table 8 Factor Loadings

	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7
Access.to.Land.		0.135		0.101		**0.618**	
Dependent.Population		-0.214	0.302	-0.107	**0.491**	-0.177	0.233
Disabled.Population	-0.220			0.354	**0.894**	0.130	
Displacement	-0.129		-0.122	**0.760**			
Distance.to.Drinking.water	**0.589**	0.152	-0.112	-0.181			-0.185
Distance.to.Medical	**0.702**						0.164
Illiterate	**0.575**			0.417	0.173		0.266
No.Fish		**0.729**	-0.247			0.101	
No.Furniture	0.159	0.427	-0.164	0.101		0.183	**0.540**
No.Livestock		**0.858**	0.153	0.198	-0.193		
No.Mattress			0.324	**0.630**	0.252		**0.595**
No.Poultry		**0.766**					
Prevalence.Stunted.Children.....			**-0.545**		-0.164		-0.154
Substandard.Housing	-0.124	0.255	-0.312	0.147		0.171	0.206
Under.nourished.		-0.107	**0.802**			0.145	-0.166
Unimproved.Drinking.Source	**0.891**		0.232		-0.205	-0.124	-0.114
Unimproved.Sanitation	**0.855**		0.133				
Without.Free.Health.Care.Drugs.			0.383	-0.116		**0.782**	

The overall social vulnerability of each district was classified through a cluster analysis of the seven factors identified above. The goal of the cluster analysis was to derive some broad characterization of social vulnerability to facilitate discussion. Clustering was performed using the k-means clustering algorithm assuming 5 clusters. Membership was well distributed among the clusters as the smallest cluster contained 15 districts and largest 39 districts. Cluster 1 shows perhaps the strongest overall vulnerability as it shows the most positive scores for among the seven factors with maximum values for Factor 3 (food quantity) and Factor 6 (access to land/free medical care). Water quality and food quality (Factors 1 and 2) also had positive scores, as did Factor 7 (lack of furniture/mattress). Displaced and dependent populations (Factors 4&5) were not found to be critical in Cluster 1. Cluster 2 is most strongly influenced by Factor 1, reflecting the potential importance of water quality to these districts. Cluster 3 is generally the least vulnerable group as its centroid is negative for all factors except Factors 6&7 which is driven by access to land/free medical and lack of furniture/mattress. Cluster 4 reflects another very vulnerable group, scoring highest in areas of displaced and dependent populations (Factors 4 and 5) and having positive values for all factors except for Factor 1. For Cluster 5 food quantity (Factor 3) remains a concern but this might be for differing reasons than in Cluster 1 as the availability of protein (Factor 2) is much lower suggesting the possibility that in these districts the issue is more about food quantity than quality.

Table 9 Cluster centroids with respect to 7 dimensions of social vulnerability

	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7
C1	0.3754469	0.304359646	1.27374737	-0.3939936	-0.6868200	1.099152705	0.3830879
C2	0.8569081	0.073357485	-0.50640580	0.1742148	-0.4238038	-0.503692025	-0.2305346
C3	-0.9144466	-0.006214268	-0.82746938	-0.4489903	-0.3672641	0.006899727	0.3210538
C4	-0.2662388	0.273571627	0.09204481	0.9114643	1.4850630	0.106733178	0.1599503
C5	-0.2876042	-1.115881148	1.10324426	-0.5279585	0.2440934	-0.509790489	-0.9567013

Output from R for statistical analysis

Use R to calc PCA using covariance matrix since all variables are on similar scale

```
> .PC <-
+
princomp(~Access.to.Land.+Dependent.Population+Disabled.Population+Displacement+Distance.to.Drin
king.water+Distance.to.Medical+Illiterate+No.Fish+No.Furniture+No.Livestock+No.Mattress+No.Poult
ry+Prevalence.Stunted.Children.....+Substandard.Housing+Under.nourished.+Unimproved.Drinking.Sou
rce+Unimproved.Sanitation+Without.Free.Health.Care.Drugs.,
+     cor=TRUE, data=Dataset)

> unclass(loadings(.PC))  # component loadings
                                       Comp.1      Comp.2        Comp.3
Access.to.Land.                   -0.19199901  0.12948604 -0.0001832685
Dependent.Population               0.11328326 -0.07381115 -0.3602510243
Disabled.Population               -0.20217477  0.10302014 -0.4171642168
Displacement                      -0.15980565  0.16247763 -0.3022995381
Distance.to.Drinking.water         0.25220294  0.20522554  0.2302991159
Distance.to.Medical                0.38027174  0.23139401  0.0684181985
Illiterate                         0.24412328  0.33964647 -0.2345072741
No.Fish                           -0.19809300  0.35180803  0.2370637375
No.Furniture                      -0.08964742  0.42218387 -0.0688292939
No.Livestock                      -0.19426006  0.35060324  0.1411106924
No.Mattress                        0.03959845  0.21944743 -0.5077257955
No.Poultry                        -0.15763585  0.35167966  0.2172148368
Prevalence.Stunted.Children.....  -0.10169395 -0.06249992  0.2781793596
Substandard.Housing               -0.22271515  0.23477859  0.0009423689
Under.nourished.                   0.14124892 -0.13597559 -0.1311583332
Unimproved.Drinking.Source         0.46745657  0.13896023  0.1002340778
Unimproved.Sanitation              0.44284020  0.18757723 -0.0002013363
Without.Free.Health.Care.Drugs.   -0.10065830  0.03121643 -0.0405589715
                                        Comp.4      Comp.5      Comp.6
Access.to.Land.                    0.209261826  0.63877682 -0.11878056
Dependent.Population               0.066924848 -0.25967038 -0.57250323
Disabled.Population               -0.051595406 -0.02924365 -0.30484036
Displacement                      -0.213592500  0.15541692  0.47031953
Distance.to.Drinking.water         0.011962899  0.11110644 -0.25121977
Distance.to.Medical               -0.046957391  0.04790837  0.01992698
Illiterate                        -0.181311450  0.11645673  0.09401078
```

```
No.Fish                           0.041380539 -0.17690405 -0.13208247
No.Furniture                     -0.016567517  0.04827868 -0.25480197
No.Livestock                      0.217028916 -0.27732378  0.29085057
No.Mattress                      -0.016465343 -0.03836388  0.17393563
No.Poultry                        0.199105262 -0.30877515 -0.04549068
Prevalence.Stunted.Children..... -0.389813226  0.27471462 -0.12729618
Substandard.Housing              -0.159572091  0.13784788 -0.05900378
Under.nourished.                  0.552106443 -0.04023421  0.16462074
Unimproved.Drinking.Source        0.057772369  0.05974495  0.12393828
Unimproved.Sanitation             0.005455132  0.09191795 -0.07326557
Without.Free.Health.Care.Drugs.   0.541863298  0.39480158 -0.06968119
                                       Comp.7       Comp.8      Comp.9
Access.to.Land.                   0.299439358 -0.081748073  0.10142774
Dependent.Population              0.181110420 -0.129913752 -0.24509343
Disabled.Population               0.161596571  0.421749273  0.12070390
Displacement                      0.218627353  0.249241094 -0.24125233
Distance.to.Drinking.water       -0.069890095  0.624674164 -0.25814555
Distance.to.Medical               0.003090179 -0.123343391  0.49191268
Illiterate                        0.087956780  0.082065824  0.21037805
No.Fish                           0.299690928  0.048442110  0.22862278
No.Furniture                     -0.236398953 -0.426597763 -0.19769421
No.Livestock                      0.122646793 -0.091439317 -0.25490372
No.Mattress                      -0.023088216 -0.220462236 -0.08596061
No.Poultry                        0.102035639  0.071404173  0.00162813
Prevalence.Stunted.Children.....  0.307743845 -0.192028732 -0.42337939
Substandard.Housing              -0.713618766  0.131715364 -0.10425538
Under.nourished.                 -0.014887143  0.114937531 -0.25049831
Unimproved.Drinking.Source        0.057439423 -0.003372264 -0.24514292
Unimproved.Sanitation             0.035761918 -0.094343818 -0.15774033
Without.Free.Health.Care.Drugs.  -0.102711287 -0.039211844  0.04927940
                                     Comp.10     Comp.11     Comp.12
Access.to.Land.                  -0.08328048 -0.34700958  0.31245892
Dependent.Population             -0.04711500 -0.10428305 -0.06384765
Disabled.Population              -0.19629895  0.17379103 -0.02879499
Displacement                      0.26033485  0.09204972 -0.25169705
Distance.to.Drinking.water        0.35187062 -0.02230990  0.14694200
Distance.to.Medical              -0.05988361  0.29114913  0.05511884
Illiterate                       -0.15024058 -0.09987775  0.28626211
No.Fish                          -0.14896844 -0.28413150 -0.45366351
No.Furniture                      0.44540371 -0.01101955  0.14839980
No.Livestock                     -0.05954528 -0.22945808  0.05502322
No.Mattress                      -0.06277646  0.15171593  0.03145118
No.Poultry                       -0.09698779  0.51094224  0.25951653
Prevalence.Stunted.Children..... -0.33472937  0.37510625  0.04744834
Substandard.Housing              -0.46975186 -0.10154456 -0.09361594
Under.nourished.                 -0.32964925 -0.02835805  0.24709827
Unimproved.Drinking.Source       -0.13823160 -0.02465942 -0.09936433
Unimproved.Sanitation            -0.15345940 -0.09529961 -0.40694363
Without.Free.Health.Care.Drugs.   0.11427883  0.39458673 -0.42519223
                                     Comp.13     Comp.14     Comp.15
Access.to.Land.                  -0.13712729  0.30067896 -0.05658355
Dependent.Population              0.19232125  0.13061280 -0.50135389
Disabled.Population              -0.16220281  0.06613429  0.44643538
Displacement                      0.18503452  0.33903668 -0.25902459
Distance.to.Drinking.water        0.17177801 -0.12296532  0.07452500
```

```
Distance.to.Medical                0.47236259  0.35658458  0.02778482
Illiterate                        -0.05637761 -0.57106834 -0.34179475
No.Fish                            0.30638537 -0.13809764  0.09797694
No.Furniture                       0.10466885  0.03638184  0.25028995
No.Livestock                       0.01271224 -0.09941516  0.02160769
No.Mattress                        0.02268903 -0.16622322  0.25771311
No.Poultry                        -0.34944575  0.21231476 -0.25284221
Prevalence.Stunted.Children.....   0.21857242 -0.18738754  0.09555133
Substandard.Housing                0.08548998  0.15139098 -0.19053987
Under.nourished.                   0.39126308  0.04148018  0.20029908
Unimproved.Drinking.Source        -0.16404356  0.10147164 -0.02873329
Unimproved.Sanitation             -0.40614484  0.15915044  0.17708028
Without.Free.Health.Care.Drugs.    0.01411155 -0.32627564 -0.18734931
                                       Comp.16     Comp.17      Comp.18
Access.to.Land.                    0.122966596  0.14434802  0.021163017
Dependent.Population               0.139121261 -0.02415169  0.002975069
Disabled.Population                0.005330403 -0.36736096  0.157954717
Displacement                      -0.186130386 -0.03882626 -0.074509290
Distance.to.Drinking.water         0.240979961  0.20386902 -0.090438484
Distance.to.Medical                0.237071515 -0.18153394 -0.058908806
Illiterate                        -0.239855592 -0.16391827 -0.105030685
No.Fish                           -0.236812593  0.29782487  0.099262525
No.Furniture                      -0.368165250 -0.17352842  0.058255832
No.Livestock                       0.501875251 -0.44209833 -0.073341882
No.Mattress                        0.356185918  0.59253018  0.059141408
No.Poultry                        -0.162323167  0.22826972 -0.065808962
Prevalence.Stunted.Children.....   0.020764356 -0.05105553 -0.062084369
Substandard.Housing                0.047399345  0.02920681  0.022011138
Under.nourished.                  -0.376799755  0.01047954 -0.164588996
Unimproved.Drinking.Source        -0.071768158 -0.05170762  0.768770419
Unimproved.Sanitation             -0.059444770 -0.02528335 -0.543830240
Without.Free.Health.Care.Drugs.    0.094786620 -0.12801645  0.041460883

> .PC$sd^2  # component variances
   Comp.1    Comp.2    Comp.3    Comp.4    Comp.5    Comp.6    Comp.7    Comp.8 
3.4247378 2.9201523 2.4750243 1.9199152 1.2338939 1.0716635 0.8811879 0.7649437 
   Comp.9   Comp.10   Comp.11   Comp.12   Comp.13   Comp.14   Comp.15   Comp.16 
0.6046746 0.4395494 0.4212500 0.3701991 0.3340142 0.2974612 0.2726630 0.2375202 
  Comp.17   Comp.18 
0.1999932 0.1311566 

> summary(.PC) # proportions of variance
Importance of components:
                          Comp.1    Comp.2    Comp.3    Comp.4     Comp.5
Standard deviation     1.8506047 1.7088453 1.5732210 1.3856101 1.11080777
Proportion of Variance 0.1902632 0.1622307 0.1375013 0.1066620 0.06854966
Cumulative Proportion  0.1902632 0.3524939 0.4899952 0.5966572 0.66520686
                           Comp.6     Comp.7     Comp.8     Comp.9    Comp.10
Standard deviation     1.03521180 0.93871610 0.87461059 0.77760827 0.66298521
Proportion of Variance 0.05953686 0.04895488 0.04249687 0.03359303 0.02441941
Cumulative Proportion  0.72474372 0.77369860 0.81619547 0.84978851 0.87420792
                          Comp.11    Comp.12    Comp.13    Comp.14    Comp.15
Standard deviation     0.64903773 0.60843989 0.57793961 0.54540005 0.52217139
Proportion of Variance 0.02340278 0.02056662 0.01855634 0.01652562 0.01514794
Cumulative Proportion  0.89761070 0.91817731 0.93673366 0.95325928 0.96840722
```

```
                          Comp.16    Comp.17    Comp.18
Standard deviation     0.48736041 0.44720599 0.36215554
Proportion of Variance 0.01319556 0.01111073 0.00728648
Cumulative Proportion  0.98160279 0.99271352 1.00000000
```

Step 2 Factor Analysis

> .FA

```
Call:
factanal(x = ~Access.to.Land. + Dependent.Population + Disabled.Population +     Displacement +
Distance.to.Drinking.water + Distance.to.Medical +     Illiterate + No.Fish + No.Furniture +
No.Livestock + No.Mattress +     No.Poultry + Prevalence.Stunted.Children..... +
Substandard.Housing +     Under.nourished. + Unimproved.Drinking.Source + Unimproved.Sanitation
+     Without.Free.Health.Care.Drugs., factors = 7, data = Dataset,     scores = "none",
rotation = "varimax")

Uniquenesses:
                 Access.to.Land.             Dependent.Population
                           0.574                            0.524
             Disabled.Population                     Displacement
                           0.005                            0.379
      Distance.to.Drinking.water              Distance.to.Medical
                           0.545                            0.465
                      Illiterate                          No.Fish
                           0.387                            0.392
                    No.Furniture                     No.Livestock
                           0.420                            0.156
                     No.Mattress                       No.Poultry
                           0.066                            0.397
Prevalence.Stunted.Children.....              Substandard.Housing
                           0.646                            0.723
                Under.nourished.       Unimproved.Drinking.Source
                           0.288                            0.078
           Unimproved.Sanitation  Without.Free.Health.Care.Drugs.
                           0.225                            0.211
```

Loadings:

```
                                 Factor1 Factor2 Factor3 Factor4 Factor5
Access.to.Land.                            0.135           0.101        
Dependent.Population                      -0.214   0.302  -0.107   0.491
Disabled.Population               -0.220                   0.354   0.894
Displacement                      -0.129          -0.122   0.760        
Distance.to.Drinking.water         0.589   0.152  -0.112  -0.181        
Distance.to.Medical                0.702                                
Illiterate                         0.575                   0.417   0.173
No.Fish                                    0.729  -0.247                
No.Furniture                       0.159   0.427  -0.164   0.101        
No.Livestock                               0.858   0.153   0.198  -0.193
No.Mattress                                        0.324   0.630   0.252
No.Poultry                                 0.766                        
Prevalence.Stunted.Children.....                  -0.545          -0.164
Substandard.Housing               -0.124   0.255  -0.312   0.147        
Under.nourished.                          -0.107   0.802                
Unimproved.Drinking.Source         0.891           0.232          -0.205
Unimproved.Sanitation              0.855           0.133                
Without.Free.Health.Care.Drugs.                    0.383  -0.116        
                                 Factor6 Factor7
Access.to.Land.                    0.618        
Dependent.Population              -0.177   0.233
Disabled.Population                0.130        
Displacement                                    
Distance.to.Drinking.water                -0.185
Distance.to.Medical                        0.164
Illiterate                                 0.266
No.Fish                            0.101        
No.Furniture                       0.183   0.540
No.Livestock                                    
No.Mattress                                0.595
No.Poultry                                      
Prevalence.Stunted.Children.....          -0.154
Substandard.Housing                0.171   0.206
Under.nourished.                   0.145  -0.166
Unimproved.Drinking.Source        -0.124  -0.114
Unimproved.Sanitation                           
Without.Free.Health.Care.Drugs.    0.782        

               Factor1 Factor2 Factor3 Factor4 Factor5 Factor6 Factor7
SS loadings      2.835   2.229   1.601   1.433   1.274   1.189   0.958
Proportion Var   0.157   0.124   0.089   0.080   0.071   0.066   0.053
Cumulative Var   0.157   0.281   0.370   0.450   0.521   0.587   0.640

Test of the hypothesis that 7 factors are sufficient.
The chi square statistic is 56.57 on 48 degrees of freedom.
The p-value is 0.186
```

Step 3 Cluster Analysis

k-means cluster analysis for 5 clusters based on the 7 factors identified in step 2

```
> .cluster <- KMeans(model.matrix(~-1 + F1 + F2 + F3 + F4 + F5 + F6 + F7,
+   Dataset), centers = 5, iter.max = 15, num.seeds = 12)
```

```
> .cluster$size # Cluster Sizes
[1] 22 39 33 27 15
> .cluster$centers # Cluster Centroids
    new.x.F1     new.x.F2    new.x.F3   new.x.F4   new.x.F5     new.x.F6
1  0.3754469  0.304359646  1.27374737 -0.3939936 -0.6868200  1.099152705
2  0.8569081  0.073357485 -0.50640580  0.1742148 -0.4238038 -0.503692025
3 -0.9144466 -0.006214268 -0.82746938 -0.4489903 -0.3672641  0.006899727
4 -0.2662388  0.273571627  0.09204481  0.9114643  1.4850630  0.106733178
5 -0.2876042 -1.115881148  1.10324426 -0.5279585  0.2440934 -0.509790489
    new.x.F7
1  0.3830879
2 -0.2305346
3  0.3210538
4  0.1599503
5 -0.9567013

> .cluster$withinss # Within Cluster Sum of Squares
[1] 108.65894 110.93775  81.82543  48.66035  93.30084

> .cluster$tot.withinss # Total Within Sum of Squares
[1] 443.3833

> .cluster$betweenss # Between Cluster Sum of Squares
[1] 356.1525

> biplot(princomp(model.matrix(~-1 + F1 + F2 + F3 + F4 + F5 + F6 + F7,
+   Dataset)), xlabs = as.character(.cluster$cluster))

> Dataset$KMeans <- assignCluster(model.matrix(~-1 + F1 + F2 + F3 + F4 + F5 +
+   F6 + F7, Dataset), Dataset, .cluster$cluster)

> remove(.cluster)
```

Step 4. Summarize each cluster by factor

```
> numSummary(Dataset[,c("F1", "F2", "F3", "F4", "F5", "F6", "F7")],
+   groups=Dataset$KMeans, statistics=c("mean", "sd"), quantiles=c(0,.25,.5,.75,
+   1))

Variable: F1
        mean        sd  n
1 -0.9209641 0.5719555 32
2  0.8605510 0.5395899 38
3  0.3748396 1.1100427 22
4 -0.2832878 0.7946318 15
5 -0.2676755 0.4897343 27

Variable: F2
         mean        sd  n
1 -0.01000709 0.4880359 32
2  0.06989720 0.7960485 38
3  0.30336882 0.5134203 22
4 -1.08968663 1.9647031 15
5  0.27167847 0.4477136 27
```

```
Variable: F3
        mean        sd  n
1 -0.8167192 0.4404450 32
2 -0.5405365 0.4670253 38
3  1.2633952 0.5836227 22
4  1.0645944 0.4673284 15
5  0.1078441 0.2116156 27

Variable: F4
        mean        sd  n
1 -0.4318448 0.6611438 32
2  0.1613980 0.7965662 38
3 -0.3781972 0.7450243 22
4 -0.5327217 0.6535283 15
5  0.8887805 0.7003329 27

Variable: F5
        mean        sd  n
1 -0.3863197 0.7216773 32
2 -0.4045976 0.5387088 38
3 -0.7115120 0.3409208 22
4  0.2390042 0.5121556 15
5  1.4742645 0.6794737 27

Variable: F6
         mean        sd  n
1 -0.01384086 0.5237541 32
2 -0.49623700 0.5656195 38
3  1.05806900 1.3202482 22
4 -0.47988554 0.6082533 15
5  0.11928440 0.1419248 27

Variable: F7
        mean        sd  n
1  0.3601796 0.7467877 32
2 -0.2294551 0.7044301 38
3  0.3706604 0.9141054 22
4 -1.0394852 0.8984898 15
5  0.1715295 0.6330709 27
```

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