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SUMMARY REPORT

MAPPING THE EXPOSURE OF SOCIOECONOMIC AND NATURAL SYSTEMS OF WEST AFRICA TO COASTAL CLIMATE STRESSORS

OCTOBER 2014

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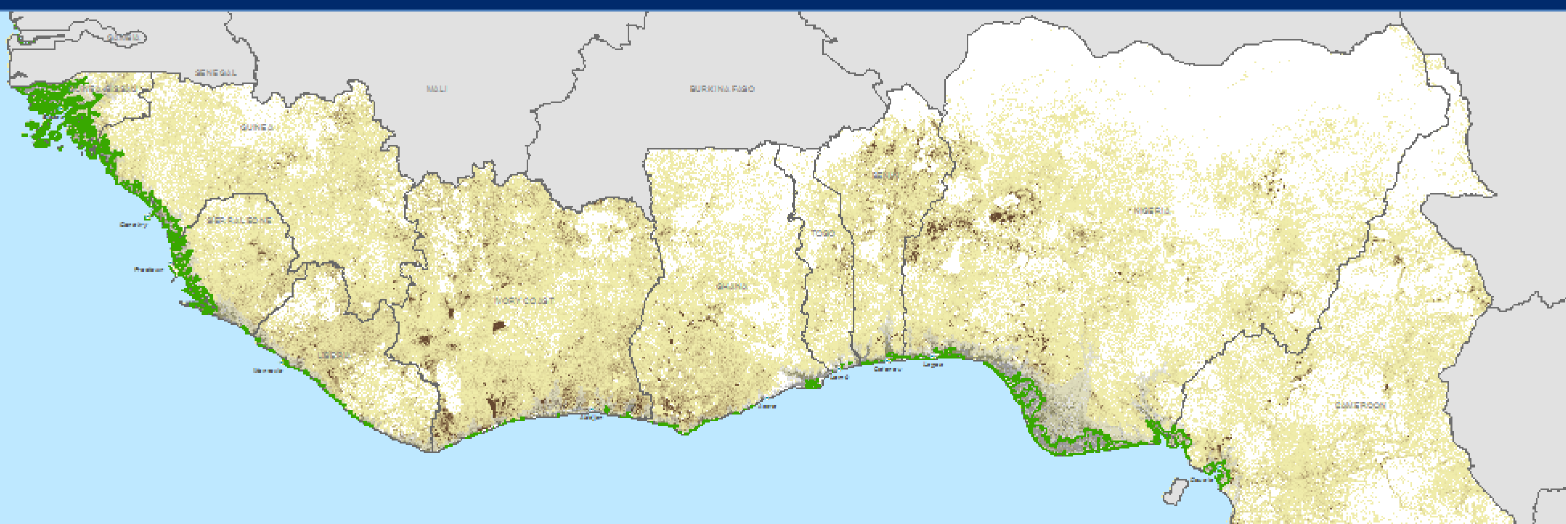

ARCC

African and Latin American Resilience to Climate Change Project

This report was prepared by a team from the Center for International Earth Science Information Network (CIESIN) at the Earth Institute of Columbia University through a subcontract to Tetra Tech ARD. Alex de Sherbinin led the team, which included Tricia Chai-Onn, Malanding Jaiteh, Linda Pistolesi, and Emilie Schnarr (geographic information system [GIS] analysts), as well as Valentina Mara (statistician).

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Cover image: West Africa mangroves, sea level rise, and deforestation.

All maps, spatial data inputs, and reports/documentation associated with this vulnerability mapping study can be found at http://ciesin.columbia.edu/data/wa-coastal.

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AFRICAN AND LATIN AMERICAN RESILIENCE TO CLIMATE CHANGE (ARCC)

OCTOBER 2014

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ACRONYMS AND ABBREVIATIONS

ACE2	Altimeter Corrected Elevations 2
ARCC	African and Latin American Resilience to Climate Change
CESR	Center for Environmental Systems Research, University of Kassel
CIESIN	Center for International Earth Science Information Network
DESYCO	Decision Support System for Coastal Climate Change Impact Assessment
DIVA	Dynamic Interactive Vulnerability Assessment
DST	Decision Support Tool
ESI	Economic Systems Index
GDP	Gross Domestic Product
GIS	Geographic information system
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature and Natural Resources
LECZ	Low-Elevation Coastal Zone
SLR	Sea-Level Rise
SRTM	Shuttle Radar Topography Mission
SSP4	Socioeconomic Pathway 4
SVI	Social Vulnerability Index
UNEP	United Nations Environment Programme
UNISDR	United Nations Office for Disaster Risk Reduction
USAID	United States Agency for International Development
USD	United States Dollars
WDPA	World Database of Protected Areas
WWF	World Wide Fund for Nature

ABOUT THIS SERIES

ABOUT THE STUDIES ON CLIMATE CHANGE VULNERABILITY AND ADAPTATION IN WEST AFRICA

This document is part of a series of studies produced by the African and Latin American Resilience to Climate Change (ARCC) project that addresses adaptation to climate change in West Africa. Within the ARCC West Africa studies, this document is part of the subseries Climate Change and Water Resources in West Africa. ARCC has also developed a subseries on Agricultural Adaptation to Climate Change in the Sahel, Climate Change and Conflict in West Africa, and Climate Change in Mali.

THE SUB-SERIES ON CLIMATE CHANGE AND WATER

Upon the request of the United States Agency for International Development (USAID), ARCC undertook the West Africa water studies to increase understanding of the potential impacts of climate change on water resources in West Africa and to identify means to support adaptation to these changes. Other documents in the Climate Change and Water Resources in West Africa series include Transboundary River Basins, Coastal Biophysical and Institutional Analysis, and An Assessment of Groundwater Management.

1.0 INTRODUCTION

The coastal countries of West Africa have diverse ethnic, cultural, and historical backgrounds, and represent relatively disparate levels of economic development, but they are united by a common pattern of having high levels of economic activity and population concentrations in the coastal zone. A high percentage of West Africa's population is concentrated in coastal cities vulnerable to sea-level rise, and the Intergovernmental Panel on Climate Change (IPCC) estimates that by 2020 more than 50 million people will inhabit the coast from the Niger delta in Nigeria to Ghana's capital city, Accra (Joiner et al., 2012). Coastal West Africa will face varying degrees of sea level rise (SLR) depending on land subsidence and uplift. The region already faces storm surges with high winds and intense wave action resulting in coastal erosion (Niang, 2012; Appeaning Addo, 2013), so this pattern is likely to increase and perhaps intensify as a result of higher sea surface temperatures (Emanuel, 2005). Our focus in this study is on the populations and economic and natural systems that are exposed to these combined seaward hazards, as well as to flooding of major rivers draining into the Atlantic. We exclude from our analysis other coastal climate change issues, such as increased sea surface temperatures and ocean acidification, that will also impact fisheries and coastal livelihoods.

This climate vulnerability mapping study covers the Guinea Current countries, extending from Guinea-Bissau in the northwest to Cameroon in the southeast. Such maps identify patterns of exposure, sensitivity, and adaptive capacity that contribute to specific constellations of vulnerability (de Sherbinin 2014). Here there is a greater focus on exposure, though we do present patterns of social vulnerability and economic activity that could represent different levels of sensitivity and adaptive capacity.

The combined population of the 10 countries in the region is 265 million people. Seven percent of that population, or 19 million people, live in the low elevation coastal zone (LECZ) of less than 10m above mean sea level (Center for International Earth Science Information Network [CIESIN], 2013). Almost half of the population, or 124 million people, live within 200 km of the coast (CIESIN, 2012). Although there have been Africa-wide assessments of the likely impacts of SLR and storm surge on coastal areas (Hinkel et al., 2012), and broader vulnerability mapping has been conducted for the continent (Lopez-Carr et al., 2014; Busby et al., 2013; Thornton et al., 2008), there has been no focused assessment to date on the likely exposure of different systems to seaward stressors among the Guinea Current countries. This study seeks to bridge that gap. The coastal fringe from Côte d'Ivoire to Nigeria is a relatively low-lying region of rapid population growth and intense economic development; as such, it is particularly vulnerable to future surge and SLR impacts.

A major purpose of this summary report is to provide a short version of methods and results to accompany poster-sized maps that were produced separately. Section 2.0 of this report provides a summary of methods and results and Section 3.0 provides high-level findings and an assessment of limitations and potential next steps. Those wishing a more detailed description should consult the full report (see URL on the inside cover), which includes a complete explanation of the methods, more detailed results, a larger set of maps, and an annex with data documentation. The same Web page includes the poster-sized maps for download.

2.0 SUMMARY METHODS AND RESULTS

For this study, we needed to measure four things:

- Exposure levels;
- Exposure of populations and their vulnerability and adaptive capacity;
- Exposure of economic systems; and
- Exposure of natural systems.

Here we provide a summary of each of these in turn.

2.1 EXPOSURE LEVELS

In this study the coastal zone is defined as a 200km strip from the coastline inland, a broad definition that includes immediately exposed systems and those that are largely dependent on coastal economic and natural systems. We used best available data on coastal elevation from Altimeter Corrected Elevations 2 (ACE2) (Berry et al., 2008) and flood risk (United Nations Environment Programme/United Nations Office for Disaster Risk Reduction [UNEP/UNISDR], 2013) to identify areas at potential risk of inundation from sea level rise, surge, or river-bank flooding. In the absence of more detailed modeling studies assessing surge risk and likely future relative changes in sea level for coastal West Africa, we define the areas at risk of sea level rise and storm surge as being in the LECZ, with separate SLR bands defined for the poster-sized maps (0–2, 2–4, 4–6, 6–10, and 10–20 meters) and for the smaller scale report maps (0–5, 5–10, and 10–20 meters). Owing to data gaps and time constraints, we were unable to model combinations of storm surge and SLR. A comparison of ACE2 elevation data with modeled SLR/surge estimates by Dasgupta et al. (2009), who used the Dynamic Interactive Vulnerability Assessment (DIVA) model, found that the DIVA results returned higher elevations in forested coastal areas, a known issue with any methods based on Shuttle Radar Topography Mission (SRTM) data. In dense canopy cover areas, SRTM measures the height of the canopy rather than ground-level elevation. ACE2 uses radar altimeter data to adjust SRTM data in densely forested environments, more accurately reflecting land elevation. It is our sense that the ACE2 elevation bands approximate levels of exposure that are appropriate for a regional-scale approach in this heavily forested coastal environment.

2.2 EXPOSURE OF POPULATIONS, VULNERABILITY, AND ADAPTIVE CAPACITY

Social vulnerability is variously defined in the literature, and a range of spatial indices have been created to represent differential patterns of vulnerability (de Sherbinin, 2014). Each definition and approach has different purposes. Our primary purpose was to create a Social Vulnerability Index (SVI) that would represent the population's exposure to coastal impacts as well as the poverty, education, and conflict levels that might indicate higher levels of "defenselessness." The spatial indicators included population density (2010), population growth (2000–2010), subnational poverty and extreme poverty (2005), maternal education levels (circa 2008), market accessibility (travel time to markets), and conflict data for political violence (1997 to 2013). High values on the raw scale for each of the indicators result in higher vulnerability scores on the 0–100 scale. The indicators were averaged, with maternal education receiving double the weight (the rationale for this is provided in the full report), to produce the overall SVI (Figure 2.1). A combination of high population density, high population growth, and conflict make the Niger Delta and Lagos a "hotspot" of vulnerability in the LECZ. Abidjan (Côte d'Ivoire) also appears as a hotspot, though the political violence there has largely subsided since 2011. Other high-vulnerability areas on the coast include Conakry (Guinea), Freetown (Sierra Leone), Accra and Cape Coast (Ghana), Cotonou (Benin), and Douala (Cameroon).

Working with colleagues at Baruch College, CIESIN also developed spatially explicit projections of the region's population to 2050 using assumptions contained in the Socioeconomic Pathway 4 (SSP4) (O'Neill et al., 2014), which reflects a divided world with high rural-to-urban migration (Figure 2.2). Table 2.1 provides the projected population to 2050 in the three LECZ bands, 0–5, 5–10, and 10–20. Based on these projections, the increase in the exposed population is dramatic: there is a more than three-fold increase in population in the 0–5m LECZ band from 2010 to 2050, from 15.4 to 56.6 million people, with 73 percent of the total (41.5 million) in Nigeria. For the broader LECZ, some 115 million people in the region will live between 0–20m elevation, compared to 33 million today.

FIGURE 2.1: SOCIAL VULNERABILITY INDEX

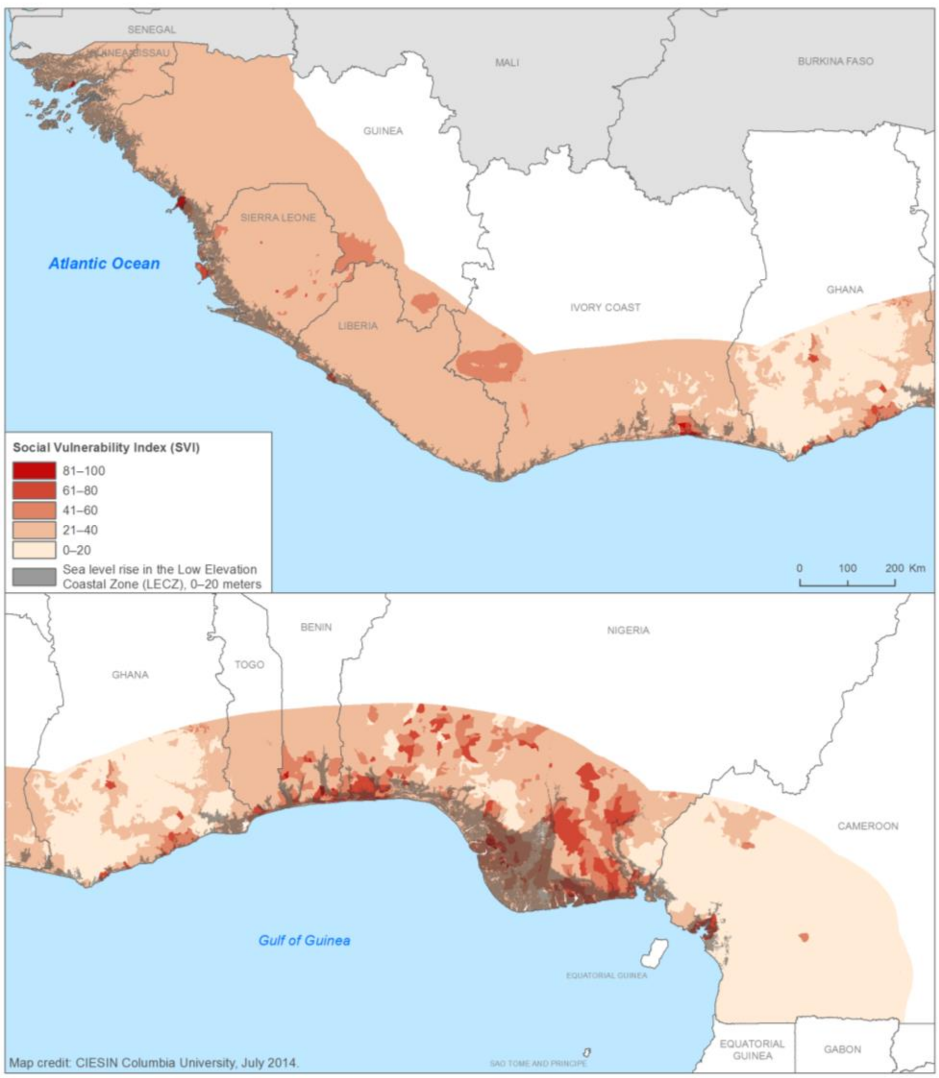


FIGURE 2.2: CHANGE IN POPULATION FROM 2010–2050

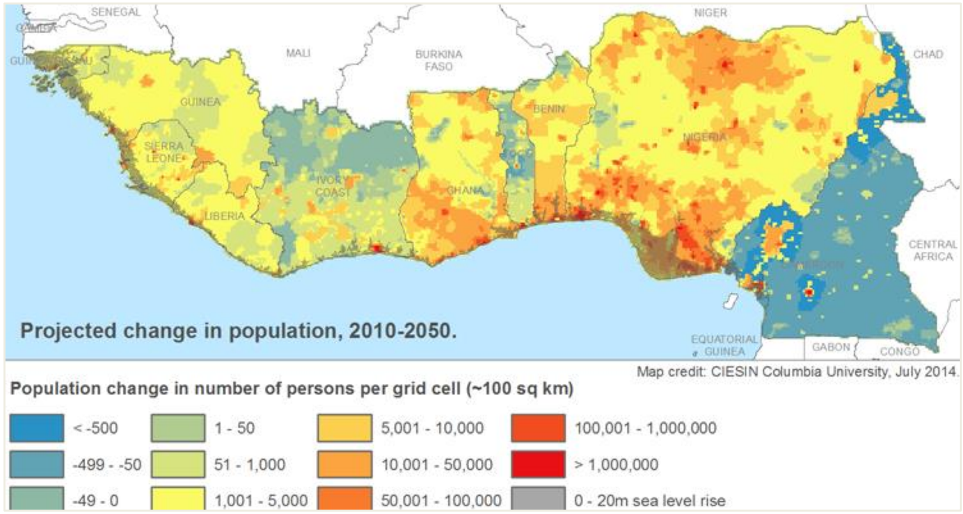


TABLE 2.1: PROJECTED POPULATION IN LECZ IN 2050

	Low-Elevation Coastal Zone			
Country	**0–5m**	**5–10m**	**10–20m**	**Total**
Benin	2,302,618	532,252	755,612	3,590,482
Cameroon	1,692,305	1,174,391	1,178,763	4,045,458
Ghana	864,562	527,778	1,613,495	3,005,835
Guinea	1,731,232	204,946	342,059	2,278,237
Guinea-Bissau	510,810	227,061	460,644	1,198,515
Côte d'Ivoire	1,690,100	583,759	856,590	3,130,450
Liberia	4,797,432	1,013,893	608,597	6,419,923
Nigeria	41,577,719	18,459,392	28,316,341	88,353,452
Sierra Leone	499,025	225,713	371,710	1,096,447
Togo	988,469	581,211	852,616	2,422,296

2.3 EXPOSURE OF ECONOMIC SYSTEMS

To measure the exposure of economic systems, we created an Economic Systems Index (ESI), the goal of which was to show relative levels of economic activity that would be exposed to seaward hazards. The ESI comprises the following indicators: gross domestic product (GDP) (gridded); urban built up areas; and a combination of cocoa, coconut, palm oil, rubber, and banana production (metric tons). For crops, we focused on higher-value export crops rather than on grains. For each of the indicators, high values on the raw scale result in higher ESI scores on the 0–100 scale (Figure 2.3). There are very high levels of economic exposure in the Niger Delta; Lagos; and in Cotonou, Benin; and slightly lower levels in Lomé, Accra, Abidjan, Monrovia, Freetown, and Conakry. Figure 2.4 provides a close up picture of the levels of exposure in Lagos and Cotonou. Using the gridded GDP data set, we calculated the GDP in the 0–5m band, and found that there is roughly United States Dollars (USD) 5.5 billion of economic activity in Nigeria, 10 times the economic exposure of the next highest countries, Benin and Côte d'Ivoire, with roughly USD 0.5 billion each. In addition to the ESI, we overlaid urban built up areas and the West Africa road network with the LECZ and flood risk layers to assess urban areas and road networks at potential risk of flooding (Figure 2.5). Road networks along the coast from Côte d'Ivoire to Lagos are particularly at risk of coastal inundation. Although the resolution of the flood risk data are relatively coarse, the broad patterns show that flood risk is highest in Sierra Leone; western Ghana; coastal Togo; Benin; and near Lagos, Nigeria. This suggests that roads may be regularly inundated or washed out with a combination of heavy rainfall and storm surge.

FIGURE 2.3: ECONOMIC SYSTEMS INDEX (ESI)

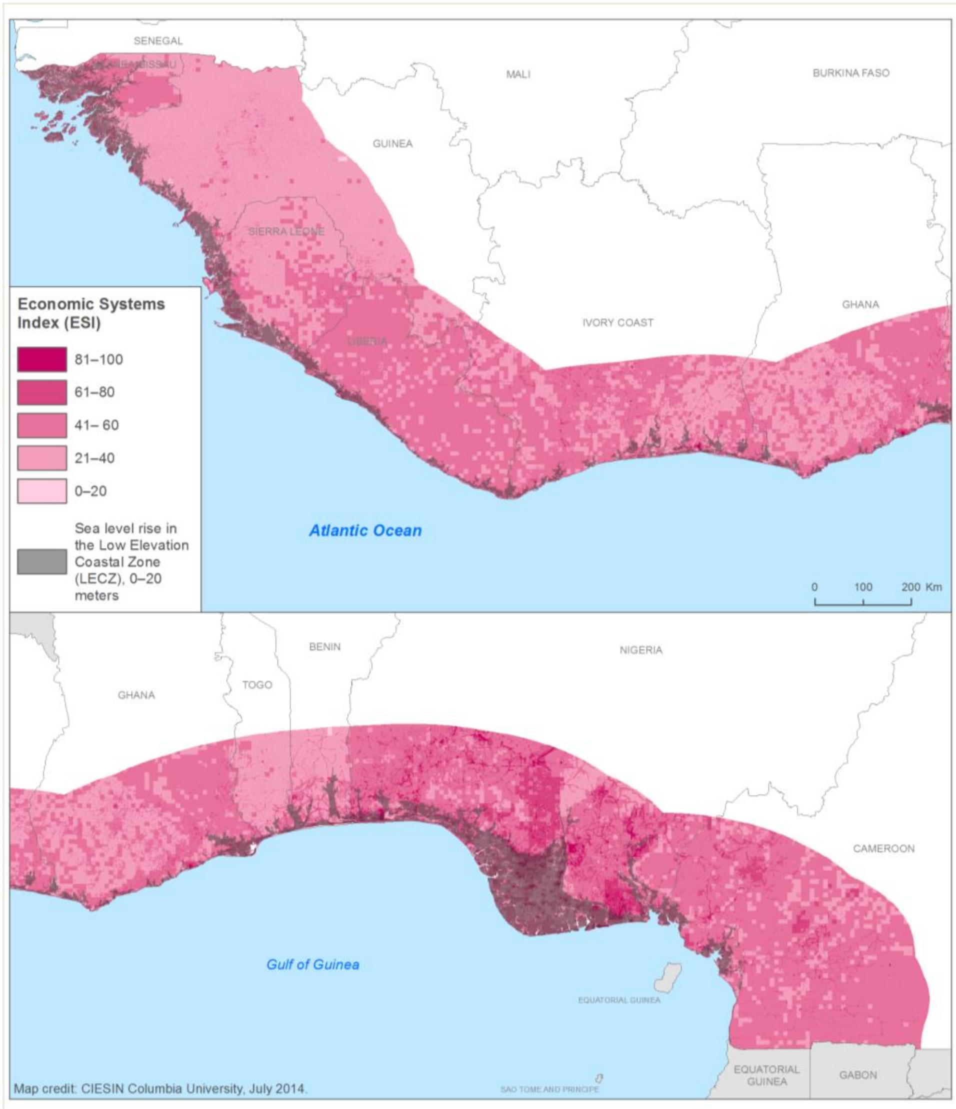


FIGURE 2.4: URBAN AREAS AND LECZ FOR LAGOS AND COTONOU

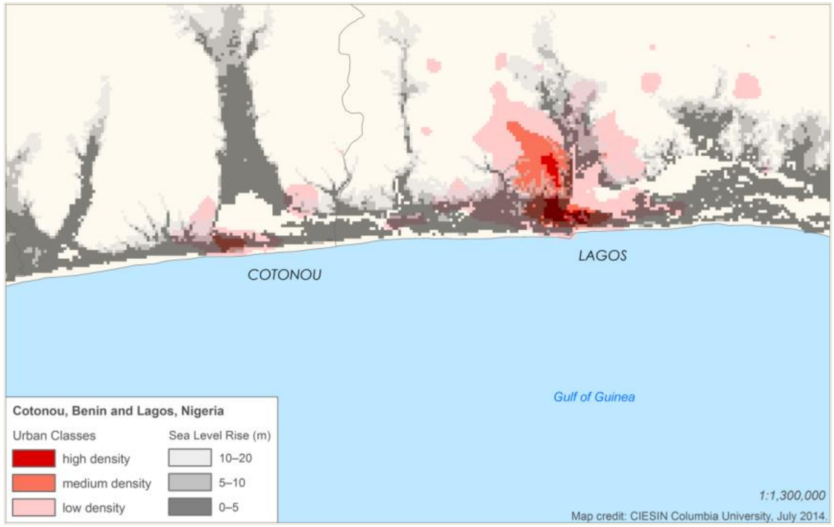
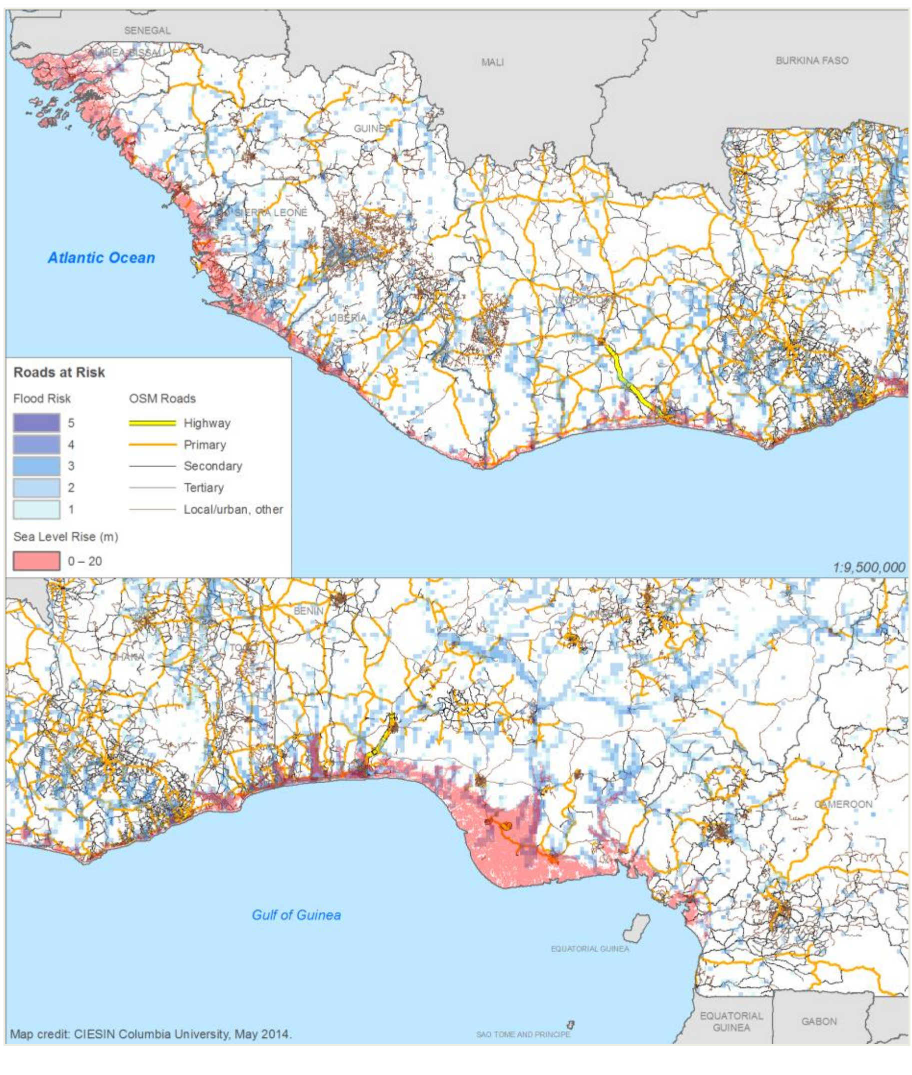


FIGURE 2.5: ROAD NETWORKS, FLOOD RISK, AND THE LECZ

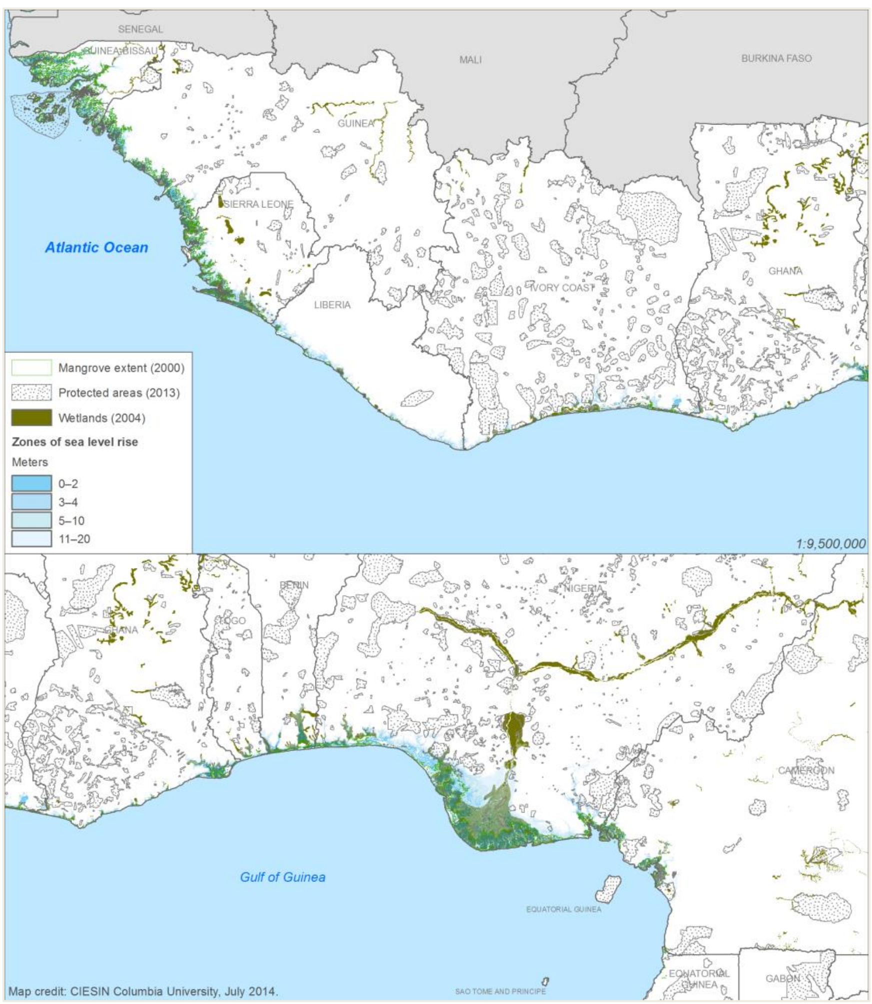


2.4 NATURAL SYSTEMS

For natural systems we were interested in the intersection of seaward hazards with mangrove forests (Giri et al., 2010), forest cover loss from 2000–2012 (Hansen et al., 2013), wetlands from the Global Lakes and Wetlands Database: Lakes and Wetlands Grid (World Wide Fund for Nature [WWF] and the Center for Environmental Systems Research, University of Kassel [CESR], 2013), and threatened mammals, amphibians, and birds based on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List database. We did not create an index for natural systems since there was no logical way to do so. Figure 2.6 presents the wetlands map (including an outline of the mangroves) along with protected areas from the World Database of Protected Areas (WDPA). In general, mangroves will be highly susceptible to SLR impacts because they thrive in brackish waters that are at or just above sea level (Ellison and Zouh, 2012). The degree to which mangroves, sea grasses, marshlands, and estuaries can migrate inland as sea level rises will in part be determined by the degree of protection around the larger wetland area (de Sherbinin et al., 2012) and the buffer between the natural system and the built environment. The Bijagos islands of Guinea-Bissau have the greatest protection (although the management capacity may be limited); apart from this park, in the rest of West Africa, there are only four small marine protected areas in Côte d'Ivoire and one in the Niger Delta.

In the full report, there are also maps depicting areas experiencing high rates of deforestation, as well as ones showing areas with high concentrations of threatened species (mammals, birds, and amphibians).

FIGURE 2.6: WETLANDS, PROTECTED AREAS, AND THE LECZ



3.0 CONCLUSIONS AND LIMITATIONS

This preliminary study of coastal vulnerability in West Africa highlights both a number of areas of high vulnerability and risk, but also has some limitations owing to a combination of mapping scale, data gaps, and uncertainties. Taking these in turn, areas of high population and social and economic exposure in the LECZ include the Niger Delta; Lagos; and Cotonou, Benin. This has to do with the intense urban and economic development in these areas. Projections suggest that population numbers for Nigeria and Benin in the 0–20m band could rise from 22 million today to 92 million in 2050. In the Delta these patterns are associated with oil and gas exploitation and high levels of poverty and conflict. Coast lines tend to rise more steeply in the western portions of the region, from Guinea to Liberia, resulting in lower levels of overall exposure. Côte d'Ivoire, Ghana, and Togo lie somewhere between these two extremes. Accra, for example, has the advantage of being largely outside the 20m elevation LECZ. Guinea-Bissau is low-lying but is thinly populated with very little in the way of economic assets exposed. Overall, the combination of armed conflict, economic assets, population density (in Lagos, Benin City, Delta, and Port Harcourt), and projected population growth puts Nigeria at the top of the list of high-exposure countries in West Africa. In terms of natural systems, the coastal mangroves, salt marshes, estuaries, and lagoons of West Africa are all highly vulnerable to seaward stressors while simultaneously providing a buffering capacity against storm surge. These systems are currently under-protected.

Turning to the limitations, the scale and spatial resolution of the vulnerability maps represents a relatively coarse level of analysis that masks substantial sub-regional and local detail. While most data were available at 30 arc-second resolution (~1 sq. km at the equator), processes of coastal inundation obviously operate at much finer resolutions. Urban-scale assessments would require higher resolution spatial data, such as ACE2's 3 arc-second elevation grids (or better yet, LIDAR elevation data) and detailed street, infrastructure and building data sets.

Data gaps are a perennial problem in any vulnerability mapping exercise, and this problem is exacerbated when there is a need for consistent cross-country data sets covering large regions. The following data would have been useful to the present analysis but could not be located:

- Exposure data:
  - Spatially explicit rates of relative sea level rise since 1950;
  - Spatially explicit projections of sea level rise to 2050 and 2100; and
  - Detailed bathymetric, coastal topography, and wind field data to model storm surge.
- Social vulnerability data:
  - Higher resolution poverty and adaptive capacity data.
- Infrastructure data:
  - Power plants;
  - Industrial facilities; and

- Complete and spatially accurate roads data.

- Natural systems data:
  - Bird nesting areas;
  - Areas of high endemism;
  - Areas of habitat loss (partially fulfilled by the deforestation data); and
  - Coastal erosion rates.

There are a number of uncertainties inherent in any assessment of this kind. Some of the uncertainties relate to the spatial and measurement accuracy, validity, and robustness of the data included. While we sought to retain a relatively select sub-set of data with higher accuracy (e.g., by comparing multiple data sets where available), some of the data have unknown uncertainty levels (e.g., maps of species distributions, poverty head counts, and GDP). There are also uncertainties inherent in the index creation for the SVI and ESI, such as uncertainties in thresholds for certain values on the raw scale and functional forms relationships among indicators that make up these indices (Baptista, 2014 and de Sherbinin, 2014). We do not have empirical evidence that would allow us to benchmark indicators to any "absolute" vulnerability level. Vulnerability is a construct, the outcome of complex interactions in the coupled human-environment system. It is easier to observe in the aftermath of a major shock than to measure beforehand. Since we do not fully understand the functional form of the relationship among indicators, following standard practice we assume a linear relationship between the input indicators and the indices. Yet in reality, it could be that there are threshold effects (i.e., beyond a certain value for one indicator, the system is absolutely vulnerable), or the relationship could be asymptotic (i.e., beyond a certain level an additional unit increase in an indicator value could have diminishing impacts on vulnerability).

As next steps, it is worth considering the development of higher spatial resolution impact assessments for selected areas of particular concern because of their importance for biodiversity conservation or exposure of populations or economic assets. Impact assessments vary in their sophistication, from simple overlay analyses identifying the population or land area exposed to hazards of different magnitudes (with area but not magnitude explicitly mapped) to modeling approaches based on probability distribution functions for different magnitude events that include damage functions and cost curves. One approach would be to use DIVA, but with a narrower focus on specific segments of the coast containing settlements with populations greater than 0.5 million or 1 million, analyzing results with an eye towards illuminating urban adaptation responses. A number of frameworks and risk assessment tools at the urban scale are available and could be applied and tailored to the regional context (e.g., Moench et al., 2011; Dickson et al., 2012). In lieu of DIVA, one could consider the Decision Support System for Coastal Climate Change Impact Assessment (DESYCO) decision support system (Torresan et al. 2012) with a primary focus on infrastructure and ecosystem impacts. Another option might be to take a sectoral approach, focusing on a particularly important element of the economic infrastructure for urban populations (e.g., electricity generation, water supply, or road infrastructure) and assessing likely impacts on these sectors from climate extremes (e.g., flood, surge, or drought) or longer-term projected trends. This approach would require higher-quality data inputs than were available for this study.

A spatial decision support tool ([DST] or mapping system) for West African coastal climate adaptation planning could be of use to a range of decision makers in the region. A major purpose of such a system would be to nurture a shared understanding of climate risks in the region, across multiple stakeholders, and grounded in the best science and data in order to support robust climate adaptation decision making. Although climate adaptation planning is already taking place in the region, at least to some degree, these planning processes are not always guided by a strong evidence base, and may not be grounded in a realistic view of future projections of population and economic activity. The DST would not be a "final product" as much as a process of building a system while working with stakeholders in an iterative manner. It should support transparent examination of how risks, responses, and results would be linked up across multiple sectors, multiple jurisdictions, and multiple stakeholder groups.

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