LOCATING CLIMATE INSECURITY:
WHERE ARE THE MOST VULNERABLE PLACES IN AFRICA?

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ABOUT THE CCAPS PROGRAM

This paper is produced as part of the Strauss Center's program on Climate Change and African Political Stability (CCAPS). The program conducts research in three core areas, seeking to investigate where and how climate change poses threats to stability in Africa, identify strategies to support accountable and effective governance in Africa, and evaluate the effectiveness of international aid to help African societies adapt to climate change. The CCAPS program is a collaborative research program among four institutions and led by The University of Texas at Austin.

The CCAPS program is funded by the U.S. Department of Defense's Minerva Initiative, a university-based, social science research program focused on areas of strategic importance to national security policy. Through quantitative analysis, GIS mapping, case studies, and field interviews, the program seeks to produce research that provides practical guidance for policy makers and enriches the body of scholarly literature in this field. The CCAPS team seeks to engage Africa policy communities in the United States, Africa, and elsewhere as a critical part of its research.

ABOUT THE STRAUSS CENTER

The Robert S. Strauss Center for International Security and Law at The University of Texas at Austin is a nonpartisan research center that engages the best minds in academia, government, and the private sector to develop unique, policy-relevant solutions to complex global challenges.

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EXECUTIVE SUMMARY

Africa is widely recognized as one of the continents most vulnerable to climate change. The continent's vulnerability is partly driven by geography, but also by its low adaptive capacity resulting from dysfunctions in countries' economies, health, education, infrastructure, and governance. This study is intended to be a proof of concept of a methodology for identifying which areas in Africa are most vulnerable to climate change—and why—at the most detailed scale possible. The study combines existing data on physical, socio-economic, and political insecurities to develop a holistic model of vulnerability, and then uses geographic information systems (GIS) to locate the confluence of these various types of vulnerability.

Africa is widely recognized as one of the continents most vulnerable to climate change.

The study identified four main processes that encompass different aspects of vulnerability: (1) *physical exposure to climate-related disasters*, (2) *household and community vulnerability*, (3) *governance and political violence, and* (4) *population density.* Each of these areas of vulnerability was given equal weight in the final vulnerability analysis. Within three of the four areas, several different indicators were identified that contribute to that dimension of vulnerability. Indicators within each area were assigned equal weight unless there were missing data for an indicator.

Physical Exposure to Climate-Related Disasters

The probability of exposure to an event is a fundamental part of vulnerability. The type, magnitude, and frequency of climate change impacts will vary across the African continent. Certain coastal areas will be vulnerable to rising sea levels and more frequent and intense cyclones. Other areas will be threatened by more variable precipitation patterns, which can result in more frequent and prolonged droughts and floods. The basket assessing *physical exposure to climate-related disasters* thus includes historic data of the frequency and magnitude of various climate-related disasters including cyclones, fires, floods, and droughts. It also includes an indicator for coastal areas at or below ten meters elevation to account for potential coastal inundation or storm surge impacts due to rising sea levels.

Household and Community Vulnerability

The extent to which individuals and communities are affected by natural disaster events depends, in part, on their own resources, existing health and nutrition levels, access to health and sanitation services, and levels of education. In the event of a natural disaster event, people and communities that are already sick or under-nourished, that lack access to water and health care, and that have low levels of education are more likely to experience problems than those that are healthy and well-fed, with adequate water, health services, and education. This basket thus includes indicators grouped into four categories: (1) health of the population, (2) education of the population, (3) availability of daily necessities, and (4) access to healthcare services. Less healthy populations are more vulnerable to disease, starvation, and thirst that can result from an extreme weather event. Better educated populations are more likely to have information about natural disaster vulnerability, better information about early warnings, and more ability to cope in the event of a disaster through innovation and problem-solving. Health and sanitation service indicators capture the availability of community-level resources—such as clean water, hospitals, and medical professionals—that populations use in the event of a disaster.

Governance and Political Violence

Whether or not individuals experience the worst effects of climate change will partially depend on the quality of governance in the country in which they live. Government support can enable communities to prepare for and adapt to the expected impacts of climate change and can help them respond when climate-related disasters do occur. Governments that cannot or do not meet the needs of their citizens can transform a natural phenomenon into a disaster that puts a large number of people at risk of death from starvation, disease, or exposure to the elements. In such societies, disorder and instability may also follow natural disaster events. This basket aims to capture this dimension by including a variety of measures, including government effectiveness and voice and accountability. This basket also seeks to capture the degree to which a country has a violent history, which, in certain regions, can complicate the task of providing relief supplies.

Population Density

When natural disaster events occur in densely populated areas, the impact is likely to be more severe than it would be in areas with fewer people. More people will be in need of emergency rations of food and water and medical care, and demands on existing facilities and resources may be quickly overwhelmed, especially if climate change impacts force rural populations to migrate to urban areas.

Methodology

This study collected existing data on household, community and governance variables and conducted initial data processing in Excel. Researchers then used ArcGIS to map these variables. Each of the variables in this model was initially classified into quintiles and recoded with values of one through five. All of the variables within a given basket were then summed and mapped to create composite maps for *physical exposure to climate-related disasters, household and community vulnerability, and governance and political violence vulnerability*. *Population density* was simply classified into quintiles, recoded, and mapped individually. Composite scores for each basket were then classified into quintiles again, and again recoded with values of one through five. The four baskets *(physical exposure to climate-related disasters, household and community vulnerability, governance and political violence vulnerability, and population density)* were then summed together to create a composite vulnerability. Finally, the composite vulnerability scores were classified into quintiles and mapped to create a final composite vulnerability map (Figure 5 in this paper).

Findings

The composite vulnerability map in Figure 5 shows a number of significant patterns. Areas with the greatest vulnerability are parts of Madagascar, coastal West Africa, coastal Nigeria, Ethiopia, and the Democratic Republic of Congo. More important than mere identification, however, is an in-depth examination of the drivers of this vulnerability, which can in turn inform appropriate policies and interventions. The elevated level of vulnerability does not result from the same elements in each of these places. In some cases, extreme exposure to climate-related disasters makes an area very vulnerable, and physical adaptation strategies may help reduce vulnerability. In other areas, though, poor governance or limited household and community resources for maintaining health and education may be more important than the magnitude of the physical climate-related impacts. In those cases, improving governance, reducing violent events, and improving access to health care, education, and daily necessities may do more to reduce vulnerability than physical adaptation strategies. Uniform strategies will not be effective across this diverse continent.

LOCATING CLIMATE INSECURITY: WHERE ARE THE VULNERABLE PLACES IN AFRICA?

Africa is widely recognized as one of the continents most vulnerable to climate change. The continent's vulnerability is partly driven by unfortunate geography, where the physical effects of climate change are likely to be among the most severe on the planet. It is also largely due to the low adaptive capacity of many African states, a product of problems in their economies, healthcare and education systems, infrastructure, and governance.[1]

These challenges are not uniformly distributed within Africa. In order to identify areas of vulnerability and prioritize limited resources, it is not sufficient to say "Ethiopia is vulnerable" without explaining which parts of Ethiopia are particularly vulnerable and for what reasons. Recognizing where physical exposure to climate change conjoins with other dimensions of vulnerability is an important area for research with significant policy relevance. With information on which parts of the continent are most vulnerable to climate change, Africans themselves can prioritize their scarce resources accordingly and the international policy community can better target adaptation assistance that is likely to become increasingly important.

This project is located in the larger, emergent debate about climate change and security.[2,3] The "securitization" of climate change in the policy world and among academics has largely focused on the causal connections between climate change and conflict.[4] Methodologically, most scholars take the expected effects of climate change—such as drought, rainfall variation, disasters, and migration—and look for analogues to see if those effects have historically been correlated with the onset of violent conflict.[5] To date, the findings of this literature have been mixed and somewhat disappointing, in part because of the lack of adequate data.[6] Moreover, such approaches have a number of limitations, not least of which is a truncated view of what constitutes a security problem.

With the concept of human security, some academics and practitioners sought to enlarge the concept of security to encompass almost any harm to human welfare. Such conceptual stretching may make the idea of security meaningless.[7] Climate change does, however, constitute a security concern beyond its potential contribution to violent conflict. Climate change is expected to increase the number and severity of extreme weather events.[8] Given that militaries are frequently deployed to provide humanitarian relief in the aftermath of natural disasters, such extreme weather events constitute important security concerns for external actors, if only because the diversion of military resources represents an opportunity

What makes a place potentially vulnerable to climate change?

cost and could keep military resources from being deployed for other purposes.[9]

Moreover, in poor, fragile states, like many of those in Africa, climate shocks and swift-onset meteorological disasters potentially constitute more severe threats to domestic security by compromising a state's monopoly of force within its borders.[10] In the absence of effective delivery of relief supplies, the destruction of infrastructure and interruption of services can contribute to such desperation that the populace will steal or riot to secure necessities. In such circumstances, these risks to state control are compounded if others take advantage of the absence of a security presence to loot for personal gain. Moreover, disasters may provide focal points around which citizens with grievances against the regime may rally.[11]

While the potential contribution of climate change to violent conflict is important, this research focuses more broadly on the variety of dimensions that make a country and its people vulnerable to climate change. At the same time, the security focus also makes this work broader than the United Nations International Strategy for Disaster Reduction (UNISDR), which focuses more narrowly on mortality and economic losses from meteorological disasters.[12]

What makes a place potentially vulnerable to climate change? Answering this question requires an understanding of the concept of vulnerability. As the literature on vulnerability and disasters has demonstrated, vulnerability to extreme weather events is only partially a function of environmental and geographic features.[13] In addition to living in areas prone to flooding, drought, or other extreme weather events, communities are often made more vulnerable because they are marginalized from services, infrastructure, and levers of power that might otherwise help them in times of need. They lack adequate public infrastructure (such as roads, piped water, sanitation, and electricity) or access to healthcare, education, and other basic services. These risks may be compounded by a lack of political representation, poor governance, or a history of violence in the country.

This study uses geographic information systems (GIS) to locate the confluence of these types of vulnerability in Africa. The study mapped layers of data on sub-national vulnerability to climate-related disasters

that may increase in frequency and severity due to climate change. These maps show relative vulnerability to climate change in different places by incorporating a variety of indicators. Vulnerability mapping provides a way to understand where and how climate change might constitute a threat to African security. GIS is not widely deployed in international relations scholarship but is extensively used in other fields. GIS allows users to visualize data spatially. The software also permits users to calculate spatial properties of locations or geographic shapes (such as states, provinces, or sub-national administrative units). For example, with GIS, one can calculate the number of strikes or riots that occurred in a particular province and whether these events overlap with locations where droughts have occurred. For the purposes of this study, mapping the diverse sources of historic problems in Africa at the sub-national level provides a way to understand which places might be most vulnerable to climate change in the future.

This approach ranks locations within Africa in terms of their relative vulnerability to climate change using a holistic model of vulnerability. The vulnerability rankings are relative to other African countries rather than the entire globe. Thus, countries and localities exhibiting low relative vulnerability within Africa may still be highly vulnerable to climate change compared to the world as a whole. The assessments of sub-national vulnerability presented in this paper incorporate geospatial data from a variety of sources including the Global Risk Data Platform (on disasters), the World Bank's Worldwide Governance Indicators (on government effectiveness), the Political Instability Task Force (on killings and violence), the World Health Organization's Global Health Atlas on (maternal mortality and spending on nurses), and several other data sources.

This paper opens with a discussion of vulnerability and includes a review of several exemplars of vulnerability indices. The second section presents an overview of the research team's approach to vulnerability and a detailed review of the methodology. The third section presents the findings.

The Attributes of Vulnerability

Conceptual fragmentation characterizes the literature on vulnerability. Different disciplines and professions understand the concept differently.[14]

The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) defined vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."[15]

Vulnerability is also often identified in government and scholarly assessments as being susceptible to losses. Wisner, for example, suggests that across the diverse meanings of vulnerability is the notion of "potential for disruption or harm."[16] Cardona suggests that "vulnerability in social groups could thus be understood as the reduced capacity to 'adapt to', or adjust to, a determined set of environmental circumstances."[17] In the UNISDR *Global Assessment Report*, vulnerability is defined as "a propensity or susceptibility to suffer loss and is associated with a range of physical, social, political, economic, cultural and institutional characteristics."[18] The converse of vulnerability is resilience, or the degree to which countries, communities, families, or individuals are able to insulate themselves from losses or, at the very least, have the capacity to respond quickly to emergencies and recover from them, minimizing long-term damage and loss of life.

One of the more popular conceptions of vulnerability in the literature is encapsulated by the simple equation: risk = vulnerability x hazard.[19] In this view, vulnerability is seen as a component of risk. Risk is seen as a function of both exposure to physical *hazards and vulnerability*. Brooks, Adger, and Kelly seek to operationalize this with respect to the risk of disaster mortality, where the probability that a country will be exposed to a climate-related or meteorological event and its vulnerability to this event reflect the likely consequence or importance of that event.[20] In this equation, environmental and physical factors contribute to risk, whereas vulnerability is narrowly defined in socio-economic and political terms. A focus on vulnerability as a purely social understanding could potentially be misleading. As Cardona notes, "If there is no hazard, it is not feasible to be vulnerable when seen from the perspective of the potential damage or loss due to the occurrence of an event."[21] A vulnerability index based on non-physical variables would tend to under-weight the physical determinants of vulnerability.

The purpose of this study is to create an index of the diverse sources that expose people to harm, including physical, social, political, and economic sources.

Another tendency might be to focus on vulnerability purely in terms of physical exposure. Raleigh and Jordan suggest that—despite the inclusion of measures of a society's adaptive capacity in its definition of vulnerability—the IPCC definition focuses mainly on physical risks rather than the social and economic sources of vulnerability: "The

IPCC's definition of vulnerability is pointedly related to the physical risks communities experience from environmental hazards."[22] However, as Raleigh and Jordan note, scholars have long concluded that "human agency" is an important determinant of whether or not countries experience adverse consequences from physical events and are able to recover from them swiftly.

To a certain extent, the issue is a semantic one; some authors define risk and vulnerability interchangeably, while others distinguish between them. The important issue is not the name of the concept but what is being measured. The purpose of this study is to create an index of the diverse sources that expose people to harm, including physical, social, political, and economic sources.

This study captures a static snapshot of chronic vulnerability, rather than emergent, dynamic vulnerability.[23] Other organizations, like the World Food Programme and the United Nations, have parallel efforts to document and map emergent vulnerability to drought and famines.[24]

This section evaluates four exemplars of risk and vulnerability rankings, including work by Clionadh Raleigh and Lisa Jordan; research by Marc Levy et al.; papers by Nick Brooks, Neil Adger, and Mick Kelly; and work by Antoinette Brenkert and Elizabeth Malone.

Raleigh and Jordan

In their effort to capture vulnerability to disasters, Raleigh and Jordan incorporate just three dimensions: (1) GDP per capita, (2) population growth by 2050, and (3) historic disaster frequency.[25] Their intuitions are straightforward; in their view, demographic growth and limited income constitute risk factors equal to disaster frequency in contributing to a country's overall vulnerability. They provide rankings of country vulnerability to particular disasters, windstorms, droughts, and floods.[26]

A spare metric of vulnerability has some advantages. It provides a comparatively simple way to capture relative vulnerability. Limited information is required to make the calculations. Moreover, with equal weights attached to each indicator, the decision rule for aggregation requires no lengthy rationale.

However, such a lean conception does not capture the full range of contributors to state vulnerability. While any model of vulnerability necessarily simplifies reality, an overly restrictive conception is potentially less policy relevant. An index based on a few broad indicators may give little insight as to the mechanisms that give rise to underlying vulnerability. For example, income may be correlated with a variety of indicators within domains like education and health, each of which could be subject to policy interventions.

Raleigh and Jordan's ranking scheme focuses on physical sources of vulnerability (i.e. extreme weather events and population). As the disaster risk literature argues, "natural" disasters are something of a misnomer.[27] Whether an extreme meteorological event becomes a disaster (i.e. generating lasting adverse consequences on human welfare) is typically a product of governance failures and other sources of individual and community vulnerability such as inequality, poor health, or poor nutrition. Raleigh and Jordan's vulnerability scheme could benefit from inclusion of governance indicators. While governance indicators may be correlated with income, some poor countries have more capacity and willingness to insulate their populations from the worst consequences of adverse climate-related changes.

Marc Levy et al.

Emphasizing the potential security consequences of climate change, Levy et al. include several governance and political measures of vulnerability. Their paper examines where physical risks of future climate change conjoin with contemporary indicators of weak governance and political instability. Their model includes three indicators of future climate effects: (1) projected populations living in low elevation coastal zones potentially subject to sea-level rise, (2) projected temperature change and levels of adaptive capacity, and (3) simulations of future water scarcity.[28]

They combine these indicators of future climate vulnerability with three indicators of political instability: (1) a country's crisis history, (2) whether a country is located in a dangerous neighborhood, and (3) countries with low capacity. A country with high levels of two or more of these variables was identified as high risk for political instability.[29]

Levy et al.'s paper has a number of virtues. First, they incorporate models of future climate vulnerability. Historic patterns of natural disasters may not reflect future climate vulnerability, as future climate change may not take place in the regions where previous extreme weather events took place. Second, they also include several indicators of political risk and instability, which makes their work more relevant to the emergent climate security literature. Their research also includes attributes of governance thought important in disaster response. They provide a diversity of different permutations of rankings and different proximities to low elevation coastal zones, including some focused on individual indicators of political risk, some on multiple indicators of instability, and some on scenarios of future climate change.[30]

In this approach, country rankings are provided in bar charts rather than maps. Countries are identified as moderate and high risk, so some of the information about least vulnerable countries is ultimately lost

in the presentation. While the political risk indicators are aggregated in some permutations—whereby countries with high scores on two or more dimensions are defined as high political risks—the climate hazards are not aggregated so there is no single risk or vulnerability map that combines all dimensions. Like Raleigh and Jordan's method, which distinguishes vulnerable countries on the basis of particular disaster risks, Levy et al.'s approach also allows one to focus on the specific physical source of future climate vulnerability.

Yet, despite its virtues, the approach taken by Levy et al. ultimately generates a disaggregated framework and has some limitations. There is no single risk or vulnerability rating scheme, leaving readers to draw their own conclusions about which countries consistently show up among the most vulnerable lists. Their approach also leaves out other dimensions of vulnerability, particularly at the household level, which can mediate or exacerbate the physical and political sources of vulnerability included in their model.

While the inclusion of future climate risks is an important refinement, the accuracy of climate models is uncertain. Therefore, an approach that compares historical exposure to extreme climate-related events with future climate projections would offer more

information to triangulate retrospective evidence of actual vulnerability with prospective scenarios and simulations of future events.

Brooks, Adger, and Kelly

Recognizing that particular places are subject to very specific sources of vulnerability, Brooks, Adger, and Kelly seek to synthesize the diverse sources of country vulnerability to generate a portrait of global vulnerability, using generic indicators that are common processes potentially affecting all countries.

Brooks, Adger, and Kelly focus on populations' vulnerability to mortality from natural disasters. After examining 46 indicators identified in the literature as potentially relevant to vulnerability, they select eleven indicators of vulnerability to pursue for strategic assessment and construction of a global ranking of national-level vulnerability.[31]

The eleven indicators are proxies for variables from three broad areas: *education, health, and governance*. The *education* basket included three indicators: literacy rate for 15–24-year olds, literacy rate of those over 15 years of age, and the overall literacy ratio (female to male). The *health* basket included four measures: the population with access to sanitation, maternal mortality, caloric intake, and life expectancy at birth. *Governance* also encompassed four measures: two derived from World Bank governance indicators (government effectiveness and voice and accountability) and two from Freedom House indicators (political rights and civil liberties).

Brooks, Adger, and Kelly selected these eleven indicators after subjecting all 46 indicators to Monte Carlo simulations to identify which were statistically correlated with an increase in mortality to climate-related disasters.[32] They then derived weights for the variables selected based on assessments of a focus group of twelve experts. From the expert assessments and a separate assessment based on equal weights for all eleven indicators, the rankings of the indicators were as follows: (1) government effectiveness (2) voice and accountability, (3) life expectancy and sanitation tied for third, (5) literacy for 15-24-year olds, (6) political rights, (7) literacy of those over 15 years of age, (8) civil liberties, (9) literacy ratio, (10) average calorie intake, and (11) maternal mortality.

The ranking scheme offered by Brooks et al. offers an interesting methodology for determining which indicators to include in an overall vulnerability assessment. The effort to systematize indicator selection and weighting is an important contribution. As Brooks et al. argue, vulnerability assessments may often reflect idiosyncratic judgments by authors about what elements to include and

how to weight them. Their overall findings that many African countries are likely to be among the most vulnerable to climate change are valid.[33] However, the selected indicators include some that are so highly correlated with each other that inclusion of all of them does not add explanatory value, at least for African countries. For example, youth and adult literacy rates are correlated with each other at .95 within African countries. Similarly, the Freedom House indicators are highly correlated with the World Bank indicators at .90 or greater.

The construction of the index could also lead to biases and conclusions that could potentially confuse policymakers about which countries should be of highest priority. In separating the physical hazards from the more social and political determinants of vulnerability, Brooks et al. underplay the significance of geographic and physical components of vulnerability. As a consequence, countries known to be highly geographically vulnerable to climate change appear not to be worthy of concern. For example, across the thirteen separate weighting schemes, Bangladesh appeared in the upper vulnerability quintile of only one of them, principally because the underlying physical basis of the country's vulnerability drops out of their analysis.

Brenkert and Malone

Brenkert and Malone, part of a larger Pacific Northwest National Laboratory (PPNL) research team, have been developing indices of climate vulnerability since 2001 with the use of their Vulnerability-Resilience Indicator Model (VRIM). They provide mostly national rankings but have also made a preliminary effort to rank Indian states at the sub-national level.[34]

The VRIM includes seventeen indicators. Brenkert and Malone suggest vulnerability is a function of three factors: *exposure, sensitivity, and adaptive capacity*, though only sensitivity and adaptive capacity are represented in the indicators.[35] They then group indicators into sectors and each indicator is weighted equally. Under the *sensitivity* basket, they include the following sectors: food security, water resources, settlement and infrastructure, human health, and ecosystem.[36] Under the *adaptive capacity* basket, they include environmental capacity, economic capacity, and human civic resources.[37] Country *sensitivity* indicators enter as negative values so greater sensitivity reflects a net negative vulnerability, while *adaptive capacity* enters in as a positive sum. Vulnerability-resilience scores reflect the sum of negative sensitivity and positive adaptive capacity. The authors then scale these scores against global or U.S. averages.

While the Brenkert and Malone model has a number of parallels with the one developed for this study, there are some notable differences. First, as the authors themselves note, governance indicators are not included—a notable exclusion given the import of these indicators in India and the authors' own comments about the role of India's democracy. One of the inspirations for contemporary vulnerability studies is the work of economist Amartya Sen. Having observed the responsiveness of contemporary India after independence to drought and food shortages, Sen suggested that famines do not happen in democracies.[38] Government effectiveness in the expert rankings in Brooks et al. was identified as the most important indicator. Thus, the omission of governance indicators is a significant oversight that makes application of the VRIM problematic.

Second, in the Brenkert and Malone studies of India, exposure appears to largely drop out as physical risk; indicators of exposure near coasts are not accounted for except through the population indicator. The omission of governance data and the diminution of physical risk potentially make the VRIM less easy to use by practitioners. For example, in a 2009 study, the Center for Naval Analyses used the VRIM but added exposure and governance data from other sources. The result is a bit ad hoc and unwieldy since these other measures were not systematically included in the overall VRIM index.[39]

In several other papers, the PPNL research team intersects their index with projections of future climate change derived from climate models. However, the method used for coding these future projections is somewhat unclear. For example, in the Brenkert and Malone maps of country vulnerability, countries with low adaptive capacity and those facing higher temperature changes were assigned darker, more reddish colors in their ten color maps.[40] A clearer, replicable way to represent such data would be to integrate those estimates of future temperature change in an overall vulnerability or risk rating.[41]

Moreover, the data are only available for 102 countries. Only 25 of Africa's 53 countries are covered, with the Democratic Republic of Congo, Tanzania, and the Central African Republic among the notable omissions.[42] This leaves questions about potential biases in their country selection and, ultimately, utility of the model, with omitted countries being among the potentially most vulnerable (as the findings of this paper suggest).[43]

Methodology

In this study four main processes, or baskets, encompass different aspects of vulnerability: (1) *physical exposure to climate-related disasters*, (2) *household and community vulnerability*, (3) *governance and political violence*, and (4) *population density*.[44]

All four baskets have equal weight in the final vulnerability analysis. Three of the four baskets include several indicators to reflect that dimension. These indicators have equal weight within each basket, unless there are missing data for an indicator. This section outlines the intuitions behind each basket, followed by a detailed discussion of each component of the baskets.

By including climate-related disaster data in this study's vulnerability portrait, the probability of exposure to an event is established as a fundamental part of vulnerability.

Photo by Todd Smith

Physical Exposure to Climate-Related Disasters

Geographic location makes some countries more susceptible to climate change impacts. Within countries, some areas, such as the coasts, are more vulnerable to certain kinds of climate-related disasters. This study uses historic data of the frequency and magnitude of climate-related disasters, including cyclones, fires, floods, and droughts. The study also includes a measure of low-elevation coastal zones that may be susceptible to future sea level rise and higher storm surges.

By including climate-related disaster data in this study's vulnerability portrait, the probability of exposure to an event is established as a fundamental part of vulnerability.

Household and Community Vulnerability

The extent to which individuals and communities are affected by natural disaster events depends, in part, on their own resources, existing health and nutrition levels, access to health and sanitation services, and levels of education. In the event of a natural disaster event, people and communities that are already sick or under-nourished, that lack access to water and health care, and that have low levels of education are more likely to experience problems than those that are healthy and well-fed, with adequate access to water, health services, and education. Health indicators capture levels of healthiness of the population, with sicker populations more vulnerable to disease, starvation, and thirst as a result of an extreme weather event. Better educated populations are more likely to have information about natural disaster vulnerability, better information about early warnings, and more ability to cope in the event of a disaster through innovation and problem-solving. Health and sanitation service indicators capture availability of community-level resources—such as clean water, hospitals, and medical professionals—that populations use in the event of a weather disaster.

> Whether or not individuals experience the worst effects of climate-related disaster events will partially depend on the quality of governance in the country in which they live.

This basket thus includes indicators grouped into four categories: (1) health of the population; (2) education of the population;

(3) availability of daily necessities; and (4) access to healthcare services. All but two of the indicators in this basket are national level indicators.

Governance and Political Violence

Whether or not individuals experience the worst effects of climate-related disaster events will partially depend on the quality of governance in the country in which they live. Government support can enable communities to prepare for and adapt to the expected impacts of climate change and can help them respond when climate-related disasters do occur. Governments that are either so lacking in capacity or venal that they cannot or will not look after their citizens can transform a natural phenomenon into a disaster that puts a large number of people at risk of mass death from starvation, disease, or exposure to the elements. In such societies, disorder and instability may also follow natural disaster events. This basket aims to capture this dimension by including a variety of measures, including government effectiveness and voice and accountability. This basket also seeks to capture the degree to which a country has a violent history, which, in certain regions, can complicate the task of providing relief supplies.

Population Density

When natural disaster events occur in densely populated areas, the impact is likely to be more severe than it would be in areas with fewer people. More people will be in need of emergency rations of food and water and medical care, and demands on existing facilities and resources may be quickly overwhelmed, especially if climate change impacts force rural populations to migrate to urban areas.

The following section provides a more detailed description of the indicators and methodology used for each basket.

Calculating Exposure to Climate-Related Disasters

In this study, historic, geo-coded disaster data on cyclone surges and winds, floods, droughts, and wildfires is from the Global Risk Data Platform on PreventionWeb, which include data generated by UNEP/GRID-Europe.[45]

The cyclone surge frequency data is from 1975-2007 and represents events per 1000 years for category 1 cyclones. The cyclone wind frequency data is also from 1975-2007 and represents events per 1000 years, but contains data for category 1, 2, 3, 4, and 5 cyclones. Each category of cyclone frequency was classified by quintiles, and reclassified with scores of 0-5, with 0 representing no exposure, 1 the least exposure, and 5 the most exposure. These scores are represented as a final cyclone frequency raster using the following equation: Cyclone wind frequency = category 1 frequency + (category 2 frequency *2)

+ (category 3 frequency * 3) + (category 4 frequency *4) + (category 5 frequency *5). This formula assigns greater weight to stronger, more dangerous cyclones.

The flood data had no particular time frame associated with it, but is scaled to represent events per 100 years.

The drought data are represented by GRID rasters converted from individual shapefiles of drought events in each year between 1980 and 2001.[46] The model sums these individual rasters to create a drought frequency raster for years 1980 through 2001.

The wildfire density data represents the expected number of events per year per pixel, or grid cell, from 1997-2008. Some values are inexplicably high in the wildfire density GRID and will warrant further investigation in the future to determine their validity and meaning.

The rasters for each type of extreme weather event are classified by quintiles and assigned a score of 0-5, with 0 representing no exposure, 1 the least exposure, and 5 the most exposure. All GRIDs from UNEP/GRID-Europe have a 1 kilometer resolution.

In order to represent future risk from rising sea levels, this study used a digital elevation model (DEM) to extract the 1-10 meter coastal zone for all of Africa. The study selected all cells with values 1-10 and then excluded areas clearly not contiguous to the coast to increase accuracy. It is possible, however, that a few low-lying areas included in the final low-elevation coastal zone dataset would be protected from rising sea levels and storm surges by higher elevation land along the coast. The study assigned areas in the 1-2 meter coastal elevation zone a value of 5, areas in the 3-4 meter zone a value of 4, areas in the 5-6 meter zone a value of 3, areas in the 7-8 meter zone a value of 2, and areas in the 9-10 meter zone a value of 1. The DEM resolution is 30 arc seconds (1 kilometer).[47]

The study sums the six final rasters for exposure to each type of climate-related disaster, with 0-5 scores, to create a composite score of physical exposure to climate-related disasters. The quintile ranking system described above enabled the combination of different types of events without regard to how their frequency was measured. Each type of exposure received equal weight, so the final equation for exposure was as follows: Exposure to climate-related disasters = cyclone surge frequency + cyclone wind exposure + flood frequency + drought frequency + wildfire frequency + low elevation coastal zone. The highest possible value was 25 and the lowest was 0. The study classified this composite raster by quintiles as well and reclassified once more on the 0-5 scale (see Figure 1).[48]

Climate Related Hazard Exposure in Africa

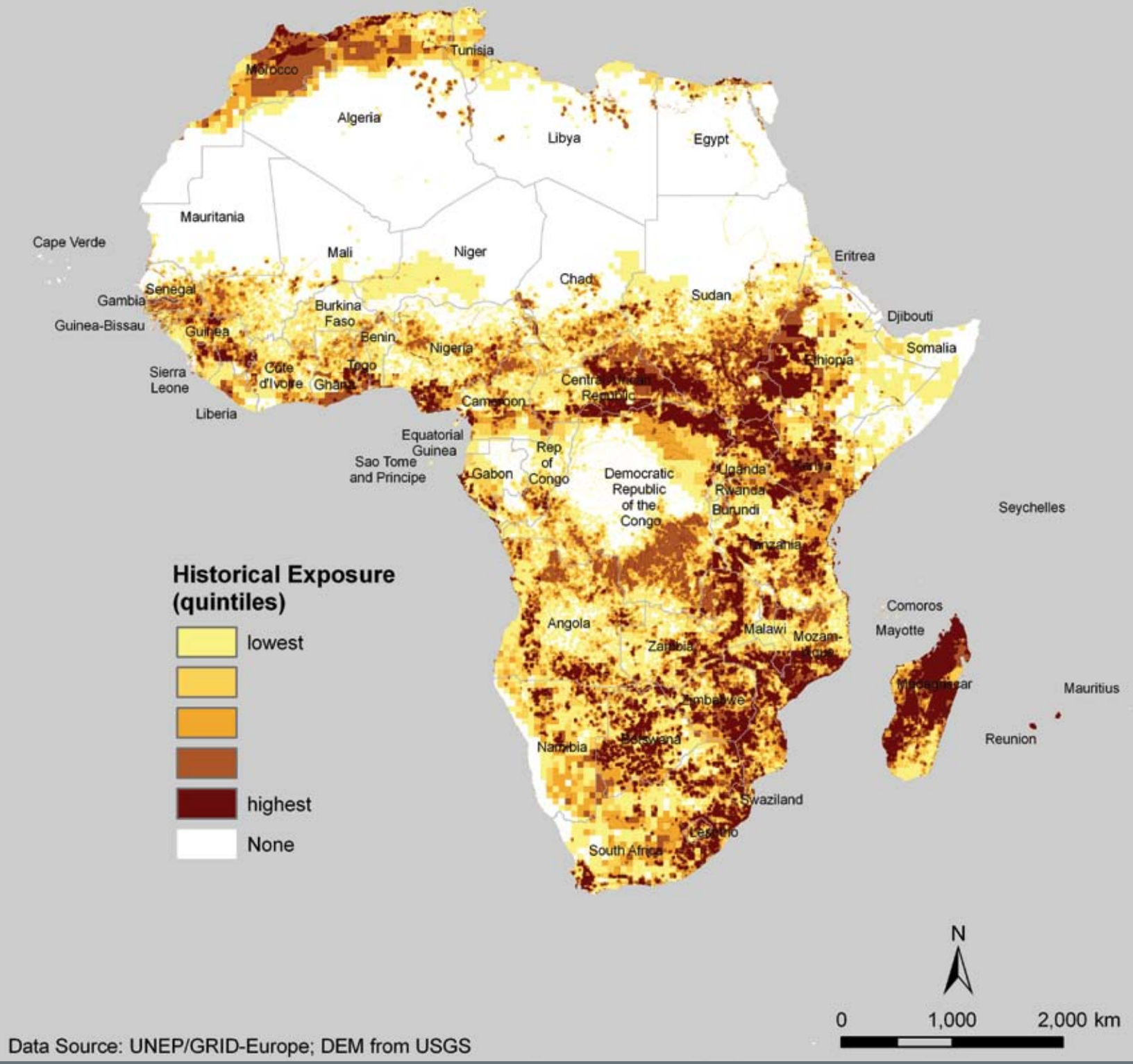


FIGURE 1

This map aggregates data on historic exposure to myriad types of climate-related disasters to assess African societies' overall physical vulnerability to the effects of climate change.

This basket measures the ability of households and communities to fulfill their own immediate needs during and after a natural disaster event.

Calculating Household and Community Vulnerability

This basket measures the ability of households and communities to fulfill their own immediate needs during and after a natural disaster event. Low levels of such capacity reflect high levels of household or community level vulnerability. Four different but related characteristics represent this capacity: (1) health of the population, (2) education of the population, (3) availability of daily necessities, and (4) access to healthcare services. This study selected fifteen national-level indicators to represent these four characteristics after an extensive review of existing literature. Brooks et al. provided empirical evidence for the statistical significance of many of these indicators. These indicators are from the World Bank's World Development Indicators (WDI), the World Health Organization (WHO), and the Food and Agriculture Organization (FAO):

1. GNI per capita, PPP (current international $)
2. Literacy rate, youth total (% of people ages 15-24)
3. Literacy rate, adult total (% of people ages 15 and above)
4. School enrollment, primary (% gross)
5. School enrollment, secondary (% gross)
6. Maternal mortality ratio (per 100,000 live births)
7. Under-5 mortality rate (both sexes)
8. Life expectancy at birth (years, both sexes)
9. Dietary Energy Consumption (kcal/person/day)
10. Dietary Protein Consumption (g/person/day)
11. Population with sustainable access to improved drinking water sources (% of total)
12. Population with sustainable access to improved sanitation (% of total)
13. Per capita total expenditure on health (PPP international $)
14. Nursing and midwifery personnel density (per 10,000 population)
15. Hospital beds (per 10,000 population)

This study uses the latest available data for each of these indicators from 1998 to 2008. The latest data point for each series was presumed to be the best proxy of the current situation in the given country and was, therefore, used in this analysis. After analysis, the study eliminated some of these indicators to develop a more parsimonious framework. The study sought to avoid giving any one variable too much weight by measuring it with two highly correlated

proxies. When two indicators bore a strong correlation, the study selected the one with more data available for African countries. For example, the study used adult literacy rates rather than youth literacy rates because the two indicators have a correlation of .9593 and there were two countries—Cameroon and Lesotho—with data available for adult literacy, but not youth literacy. Similarly, under-5 mortality is highly correlated with life expectancy at birth (.9193), and hospital beds per 10,000 is highly correlated with nursing and midwifery density (.7574). In both cases, the study used the latter indicator.

Perhaps more controversially, this study excluded Gross National Income (GNI) per capita.[49] The study originally included GNI as a proxy for household income, which is important in this vulnerability analysis. However, GNI per capita may not be the best measure of household income due to high levels of inequality for countries reliant on extractive natural resources. GNI is also reasonably correlated with other indicators—.6237 with adult literacy and .8101 with nursing and midwifery density—and the study instead chose these indicators to capture household income. This approach helped to exclude anomalous observations. For example, Equatorial Guinea has the highest GNI per capita in Africa at $21,700 (current international PPP) yet ranks 29th for maternal mortality, 43rd for life expectancy, and 35th for nursing and midwifery density.[50]

This left eight national level indicators—two in each category. The study sought to use sub-national data for the indicators where it was available. Using survey data from USAID Demographic and Health Surveys, UNDP National Human Development Reports, UNICEF statistics, and in some cases national survey data, the Center for International Earth Science Information Network (CIESIN) at Columbia University generated datasets at the level of sub-national administrative regions for the following variables:

1. Infant mortality rate (adjusted to the national 2000 UNICEF rate), and
2. Percentage of children underweight (more than two standard deviations below the mean weight-for-age score of the NCHS/CDC/WHO international reference population).

Data from the World Health Organization revealed that, at a national level, infant mortality rate was highly correlated (.8115) with maternal mortality rate.[51] The study therefore concluded that replacing maternal mortality with the CIESIN infant mortality data would obtain higher resolution insights into the health status of populations. Available national-level data closest to the CIESIN underweight children data is malnourished children data from the WHO, and these data are not as highly correlated to the FAO dietary energy consumption (.5133).[52] These data on underweight children nonetheless provide a better indicator of the availability of adequate nutrition in local communities because young children exhibit the effects of inadequate

Table 1: Indicators of Household and Community Vulnerability

Variable (weight)	Indicator (weight)	Source	Years of Data Availability
Education (.25)	Literacy rate, adult total (% of people ages 15 and above) (.125)	WDI	2000 – 2007; no data for The Gambia, Guinea-Bissau or Somalia
	School enrollment, primary (% gross) (.125)	WDI	2004 – 2008; 1998 for Angola; 1999 for Somalia; 2001 for Guinea-Bissau
Health (.25)	Infant mortality ratio (per 100,000 live births) (.125)	CIESIN	1991-2003
	Life expectancy at birth (years) both sexes (.125)	WHO	2006
Daily Necessities (.25)	% of children under age of 5 underweight (.125)	CIESIN	1991-2003
	% of Population with sustainable access to improved drinking water sources (.125)	WHO	2006; 2000 for Cape Verde and Seychelles
Access to Healthcare (.25)	Per capita total expenditure on health (PPP int. $) (.125)	WHO	2006; 2001 for Somalia
	Nursing and midwifery personnel density (per 10,000 population) (.125)	WHO	2002 – 2006; no data for Somalia

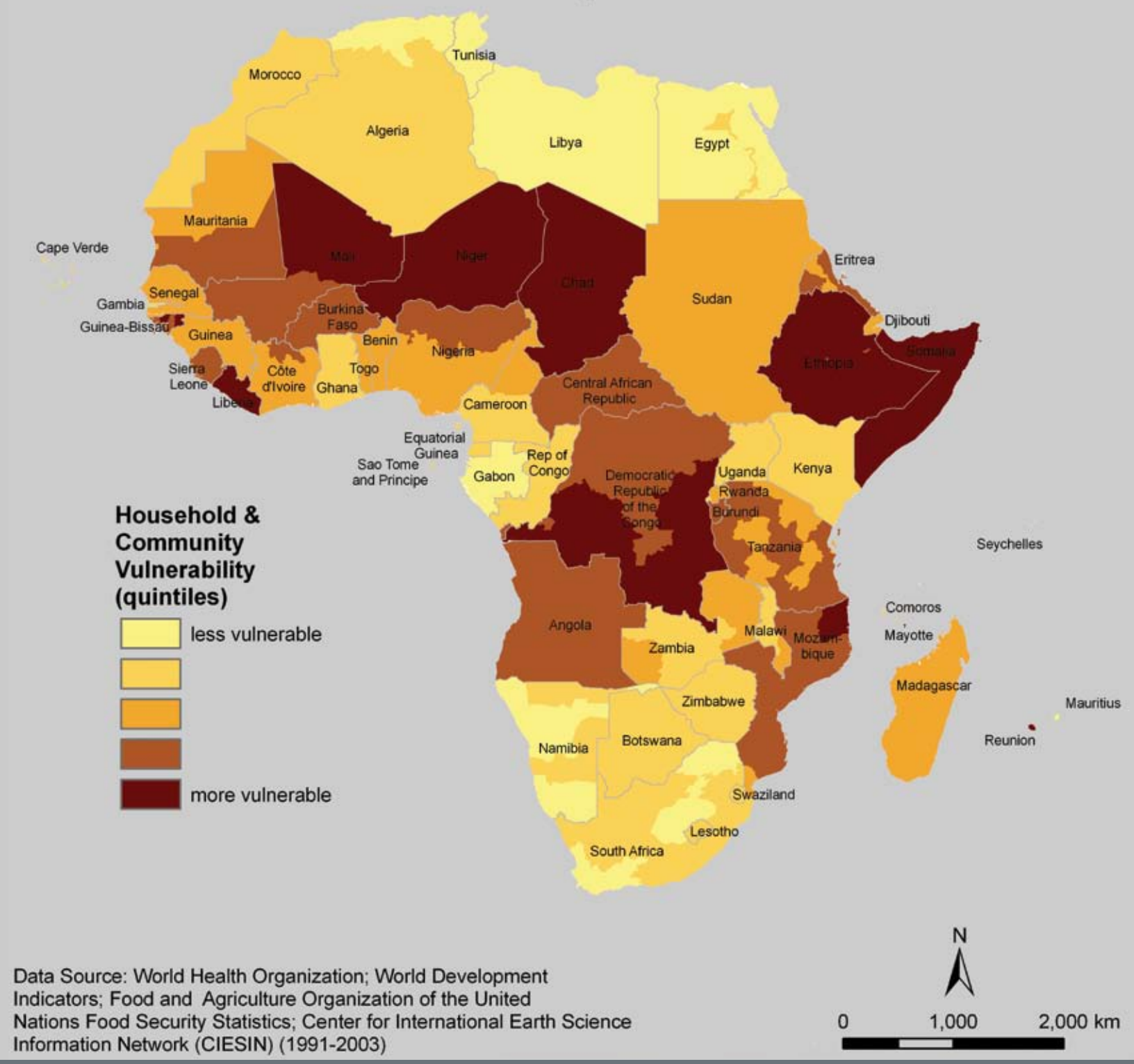
nutrition first and most noticeably. The study therefore replaced the previously included FAO energy consumption data with the CIESIN underweight children data.[53] Table 1 describes the final eight indicators included in the study and the weights applied to each within this framework.

Two indicators in the study thus use data for 542 sub-national regions in Africa. The remaining indicators use national-level data applied to all administrative regions within the country. Each percent rank score was then multiplied by the appropriate weight (0.125 if data were available for each indicator in a given variable). If one indicator for a given variable was not available, the full 0.25 weight was assigned to the other indicator. In no case was data unavailable for both indicators for a given area. Finally, these weighted percent rank scores generated a composite score for each sub-national area. All areas were then ranked.

Finally, the study classified composite scores by quintiles and assigned each a score of 1-5, with 1 representing the least vulnerable areas and 5 representing the most vulnerable areas. These data were joined to country-level administrative polygons (see Figure 2). The shapefile was then converted to a GRID raster based on the quintile scores.

Countries with the most resilience are the island nations of Seychelles and Mauritius followed closely by the north African countries of Tunisia and Libya. Countries

Household and Community Level Vulnerability in Africa



Data Source: World Health Organization; World Development Indicators; Food and Agriculture Organization of the United Nations Food Security Statistics; Center for International Earth Science Information Network (CIESIN) (1991-2003)

FIGURE 2

This map aggregates a range of education, health, and community indicators to assess African populations' vulnerability to climate change due to a lack of access to resources needed in the event of a natural disaster.

with the least household and community resilience (i.e. the highest vulnerability) are the perennially worst performers in Africa: Niger, Somalia, Chad, and the Democratic Republic of Congo.

Calculating Governance Vulnerability and Political Violence

This basket measures the potential effectiveness of any governmental response during and after a natural disaster. Five variables comprise this basket: (1) government accountability, (2) government effectiveness, (3) global integration, (4) political stability, and (5) presence of political violence. The study used national-level indicators for the first four variables to develop a national composite score for each variable. The study combined these scores with sub-national data on political violence to create a final quintile score for individual grid cells.[54]

As with household and community vulnerability, the study by Brooks et al. informed the choice of governance indicators in this study.[55] While Brooks et al. included two World Bank Governance Indicators (*voice and accountability* and *government effectiveness*) and two Freedom House indicators (*civil liberties* and *political rights*), this study includes only some of the World Bank's measures for reasons discussed below.[56]

This study excludes the Freedom House measures because they are both highly correlated with the World Bank's *voice and accountability* indicator (.9295 for *political rights* and .9511 for *civil liberties*). Furthermore, the World Bank measures appear to be more robust and reliable. They are developed using over 35 data sources from 33 different organizations as well as thousands of survey responses capturing views of the public, private, and NGO sectors. The Freedom House metrics are generated from the views of only 33 analysts and 16 academic advisors.[57] This study thus uses the two World Bank Governance Indicators, supplemented with indicators from two other data sources.

First, this study uses *voice and accountability* as a measure of how responsive a government is to the needs of its citizens. It is measured on a scale of -2.5 to +2.5 with zero representing the median country score. This study uses the 2008 scores. In general, African countries perform worse than the rest of the world. Only ten of the 53 countries considered have a positive score with the highest three scores being Cape Verde at 0.95, Mauritius at 0.88, and South Africa at 0.68. The worst performers in Africa are Eritrea with a score of -2.20, Libya at -1.90, and Equatorial Guinea at -1.89.

Second, this study uses *government effectiveness* to capture the ability of a government to implement policy in general

and, in particular, to undertake post-disaster relief operations. It is measured on the same scale as *voice and accountability* and, again, African countries generally perform poorly in relation to the rest of the world. Only six countries have positive scores, topped by South Africa at 0.75, and followed by Botswana at 0.67 and Mauritius at 0.60. The worst three performers are Somalia at -2.51, Democratic Republic of Congo at -1.89, and Comoros at -1.88.

Third, the *KOF Index of Globalization* was used as a proxy for a country's level of global integration. It uses data on three dimensions of globalization—economic, social, and political—to create an overall globalization score between zero and 100 that measures a country's level of integration in the global system. A country with a higher degree of global integration will be better positioned to obtain post-disaster assistance from the international community. Such assistance could take the form of aid from bilateral or

Photo by Todd Smith

Table 2: Composite Scores and Rankings on Government Resilience

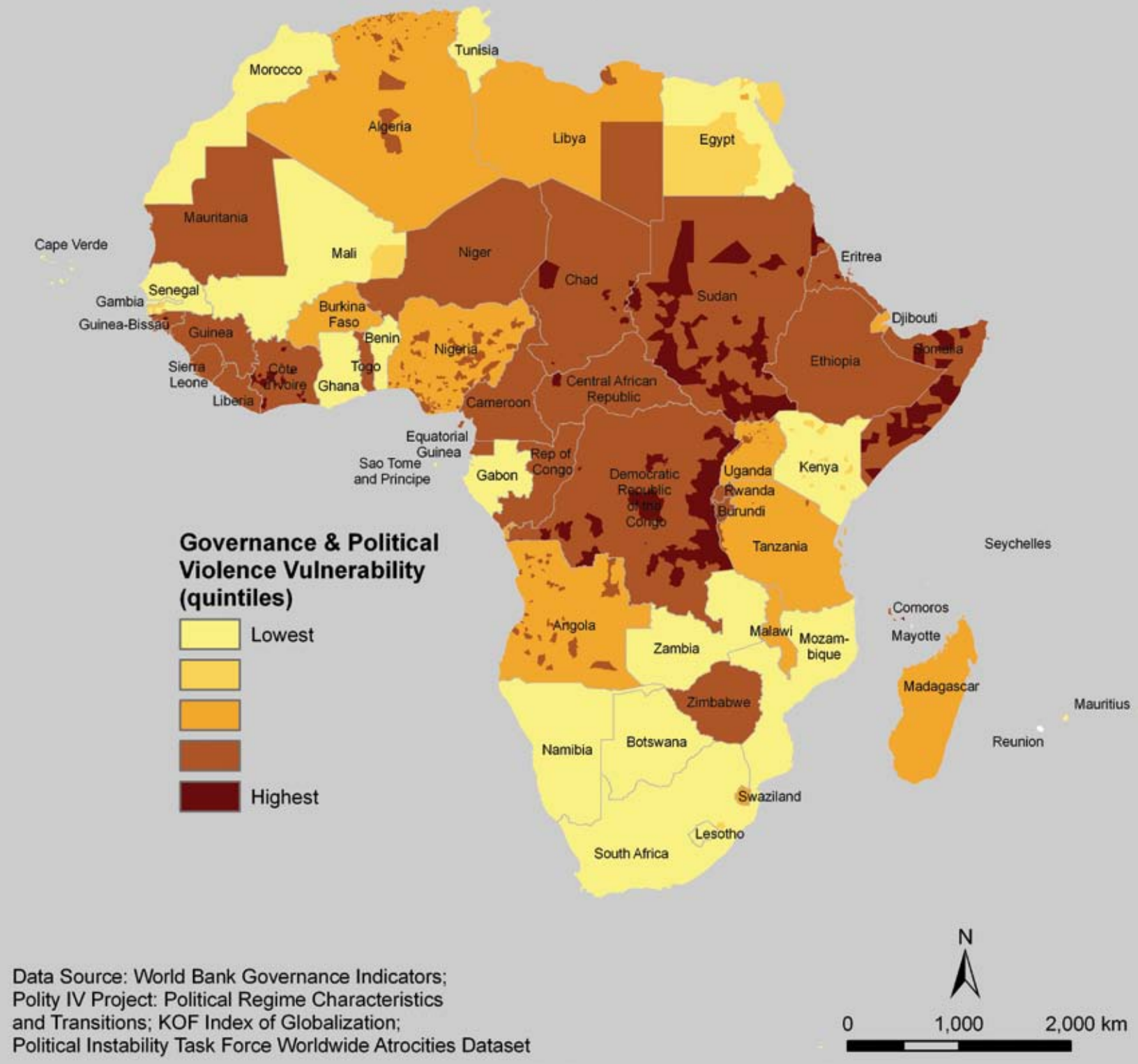
Rank	Country	Score	Quintile	Notes
1	Mauritius	0.847	1	
2	Seychelles	0.844	1	2
3	South Africa	0.819	1	
4	Namibia	0.800	1	
5	Cape Verde	0.781	1	2
6	Botswana	0.764	1	
7	Morocco	0.691	1	
8	Ghana	0.686	1	
9	Sao Tome and Principe	0.673	1	1, 2
10	Mozambique	0.648	1	
11	Tunisia	0.631	1	
12	Senegal	0.585	2	
13	Zambia	0.558	2	
14	Benin	0.556	2	
15	Lesotho	0.553	2	
16	Gabon	0.545	2	
17	Mali	0.530	2	
18	Egypt	0.496	2	
19	Kenya	0.487	2	
20	Gambia	0.481	2	
21	Malawi	0.478	2	
22	Tanzania	0.477	3	
23	Libya	0.474	3	1
24	Djibouti	0.465	3	1
25	Swaziland	0.458	3	
26	Algeria	0.455	3	
27	Madagascar	0.449	3	
28	Angola	0.446	3	
29	Nigeria	0.441	3	
30	Burkina Faso	0.416	3	
31	Uganda	0.416	3	
32	Cameroon	0.395	3	
33	Equatorial Guinea	0.377	4	1
34	Guinea	0.377	4	1
35	Rwanda	0.362	4	
36	Ethiopia	0.355	4	
37	Mauritania	0.352	4	
38	Liberia	0.337	4	1
39	Niger	0.328	4	
40	Sierra Leone	0.325	4	
41	Togo	0.323	4	
42	Republic of the Congo	0.274	4	
43	Eritrea	0.271	5	1
44	Cote d'Ivoire	0.257	5	
45	Guinea-Bissau	0.232	5	
46	Burundi	0.223	5	
47	Zimbabwe	0.223	5	
48	Comoros	0.215	5	1
49	Chad	0.211	5	
50	Central African Republic	0.167	5	
51	Sudan	0.112	5	
52	Democratic of the Congo	0.041	5	
53	Somalia	0.019	5	1, 2

Notes: 1 signifies that the country is missing Index of Globalization data.
2 signifies that the country is missing Polity IV data.

multilateral donors or international humanitarian organizations, or it could be in the form of remittances from overseas family or diasporas of the affected population.[58]

Fourth, the study used two metrics for *political stability*, as less stable governments—whether democratic or autocratic—are more easily upset by the shock of a disaster or the unrest of a stressed population. The study developed these two metrics using data from the Polity IV Project. First, the Polity IV Project reports a polity score for most countries in the world on a scale of -10, the most autocratic, to +10, the most democratic. Without preference for democracy or autocracy, this study used the difference between a country's highest

Governance Level and Political Violence Vulnerability in Africa



Data Source: World Bank Governance Indicators; Polity IV Project: Political Regime Characteristics and Transitions; KOF Index of Globalization; Political Instability Task Force Worldwide Atrocities Dataset

FIGURE 3

This map uses a variety of indicators of government effectiveness, voice and accountability, global integration, political stability, and political violence to map societies' overall vulnerability to weak governance and political violence.

and lowest polity scores in the past ten years as a measure for how much a country's government has changed. A zero indicates that the government has experienced no change, while a higher score indicates that the government has changed considerably. Comoros moved eleven points, while Kenya and Mauritania each moved ten points. Nineteen African countries have experienced no significant change. For the second metric of *political stability*, this study used a count of the total number of years since a country has undergone a major change in a single year, as reported by the Polity IV Project. In this case, a higher year count indicates a more stable government. Libya, Morocco, and Botswana have experienced the longest periods of stability with 57, 43, and 42 years respectively. Côte d'Ivoire, Mauritania, and Somalia have each experienced zero years of stability. When generating the percent ranks, the study gave each of these two metrics equal weight within the *political stability* variable.[59]

The study used the raw data for each of these four variables to generate a percent rank for each country in relation to all 53 African countries. As with the household and community resilience measure, a composite score was generated by multiplying the percent rank for each of these four variables by one-fourth and then summing them for a total governance resilience score. With values between zero and one, a higher score indicates a higher level of resilience. In the event of missing data, that indicator was simply not included and the remaining variables were weighted equally. Table 2 reports these final scores and ranks for governance resilience. The island nations of Mauritius and Seychelles had the highest composite scores followed closely by South Africa and Namibia. Somalia, the Democratic Republic of Congo, and Sudan had the lowest scores.

After determining countries' rankings on governance resilience, the study joined these data to country-level administrative polygons and converted the shapefile to a GRID raster, based on the quintile scores. Scores of 1 represent the places with the least governmental problems and scores of 5 the most problems.

Lastly, this study includes a measure of political violence, as this is thought to severely limit a government's ability to deliver emergency relief. If the government itself is responsible for the violence, it will certainly be less inclined to provide post-disaster relief. Unlike the other indicators in the governance basket that the study combined into a national-level score, political violence is assessed at a sub-national level using GIS. The study spatially joined geo-referenced data on political atrocities from the Kansas Event Data System to the highest (smallest) available administrative level and calculated

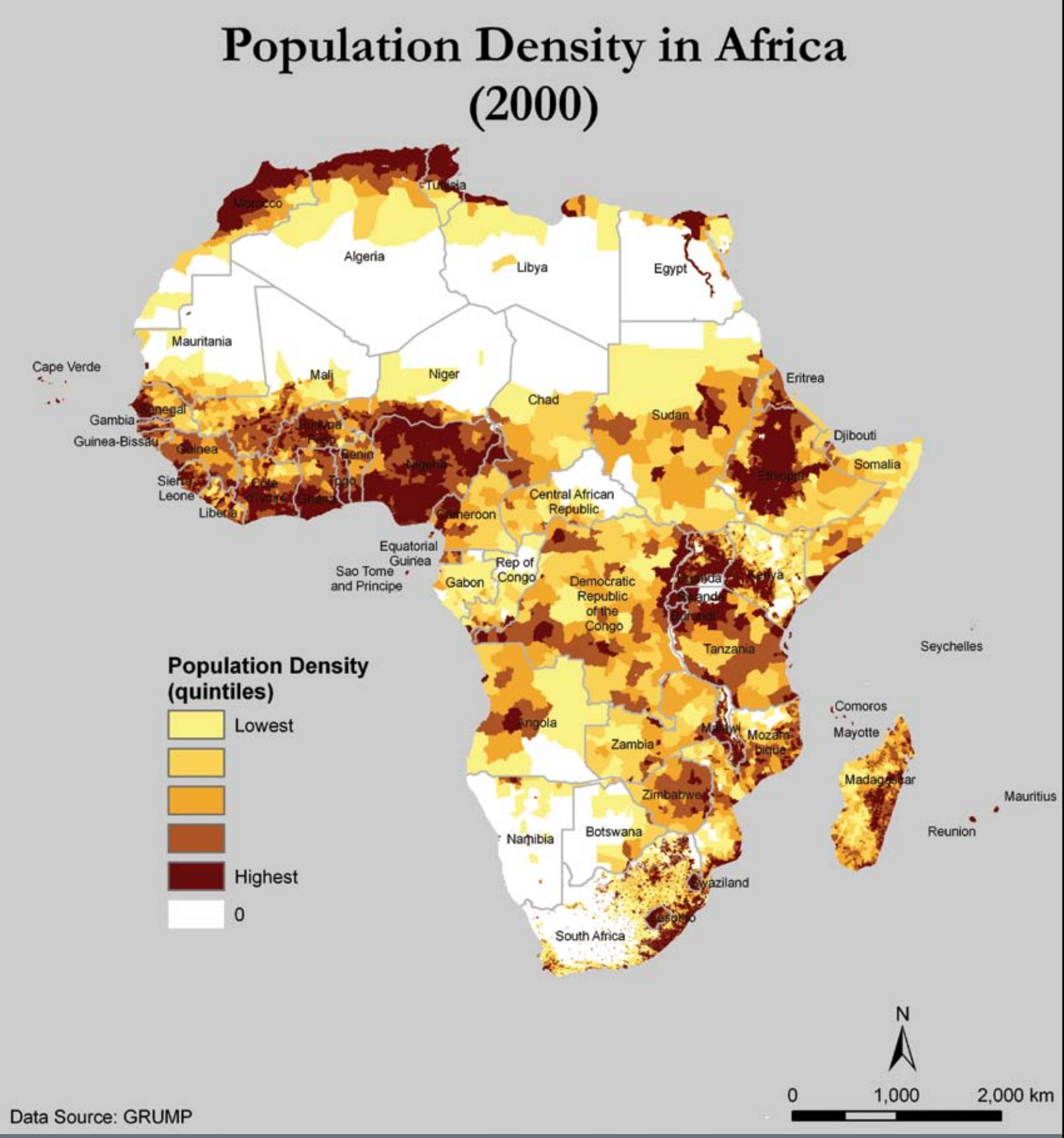


FIGURE 4

Population density in Africa is a key component in analyzing African societies' overall vulnerability to the effects of climate change.

the total number of events within each administrative area.60 The study classified administrative areas by quintiles based on the sum of events within the area (excluding all administrative areas with no events). A new field was added and populated with appropriate quintile rank scores, with a score of 1 representing the lowest vulnerability and 5 the highest. The shapefile was then converted to a GRID raster, based on the quintile rank scores, which was then summed with the governance vulnerability raster. The governance vulnerability score was assigned a weight of 0.8 because it includes four variables and the violent events data was given the remaining weight of 0.2. The final scores were then classified by quintiles to create an overall map of governance vulnerability and political violence (see Figure 3).

Calculating Population Density

Using the GRUMP population density dataset from Columbia University, the study overlaid initial findings of vulnerability with population data to find where localities of vulnerability coincide with large population concentrations.[61] The study used a population density GRID for the year 2000 with 30" resolution to account for differences in the number of people likely to be affected by a climate-related disaster in a given area. The population density GRID was reclassified into quintiles, with the first quintile containing the most rural areas—excluding areas with zero population density—and the fifth quintile containing the most urban areas. Areas with zero population density were excluded based on the idea that a climate-related even is only a disaster if it affects human populations. The population density raster was then reclassified using values from 0 to 5. Values of 1 represent the most rural areas and values of 5 the most urban areas. This is not to say that urban areas are always more vulnerable than rural areas. However, the exposure of a small number of people to a climate-related disaster will be less disruptive than exposure of a large population. The larger the affected population, the more government or foreign aid resources will be needed to respond. However, it may also be true that people living in rural areas will be more difficult to assist during and after a natural disaster, due to lack of infrastructure. Proximity to transportation infrastructure, such as paved roads and airports, is another basket of vulnerability indicators that should be examined in the future. Figure 4 shows the distribution of population density within Africa.

Findings

After combining these four components of total vulnerability, the aggregate level findings show a number of interesting patterns (see Figure 5). Areas of most acute composite vulnerability are Madagascar, coastal west Africa, coastal Nigeria,

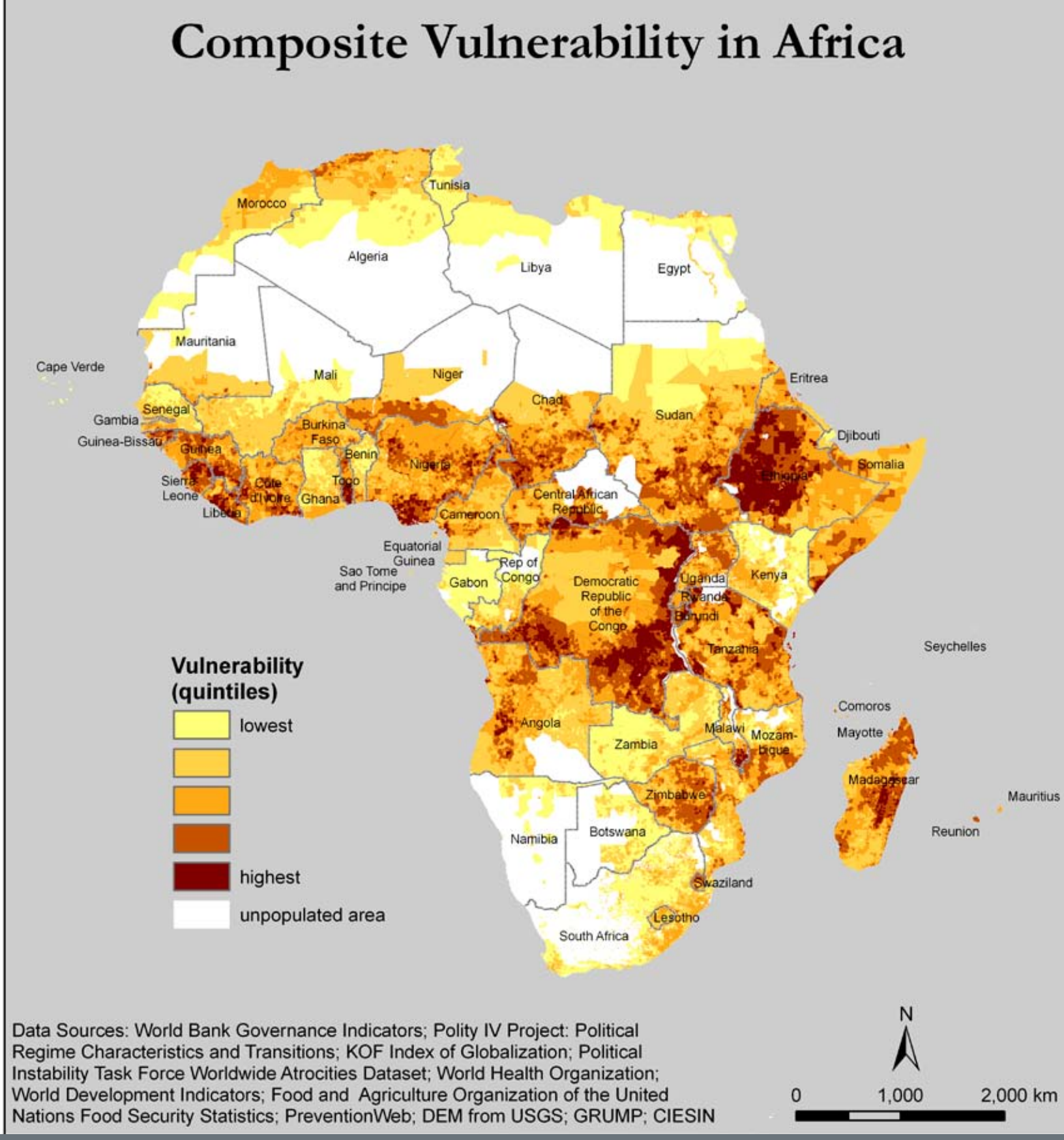


FIGURE 5

Combining these four components of vulnerability—physical exposure, household and community resources, governance and political violence, and population density—the study maps the composite vulnerability of African societies to the potential effects of climate change.

Ethiopia, and the Democratic Republic of Congo. More important than mere identification, however, this approach allows for in-depth examination of the drivers of this vulnerability, which can in turn inform appropriate policies and interventions.

Madagascar's vulnerability is primarily driven by exposure to cyclones, wildfires, and rising sea levels in densely populated low-elevation coastal areas (see Figure 6).

Similarly, coastal regions of many west African states are particularly vulnerable due in part

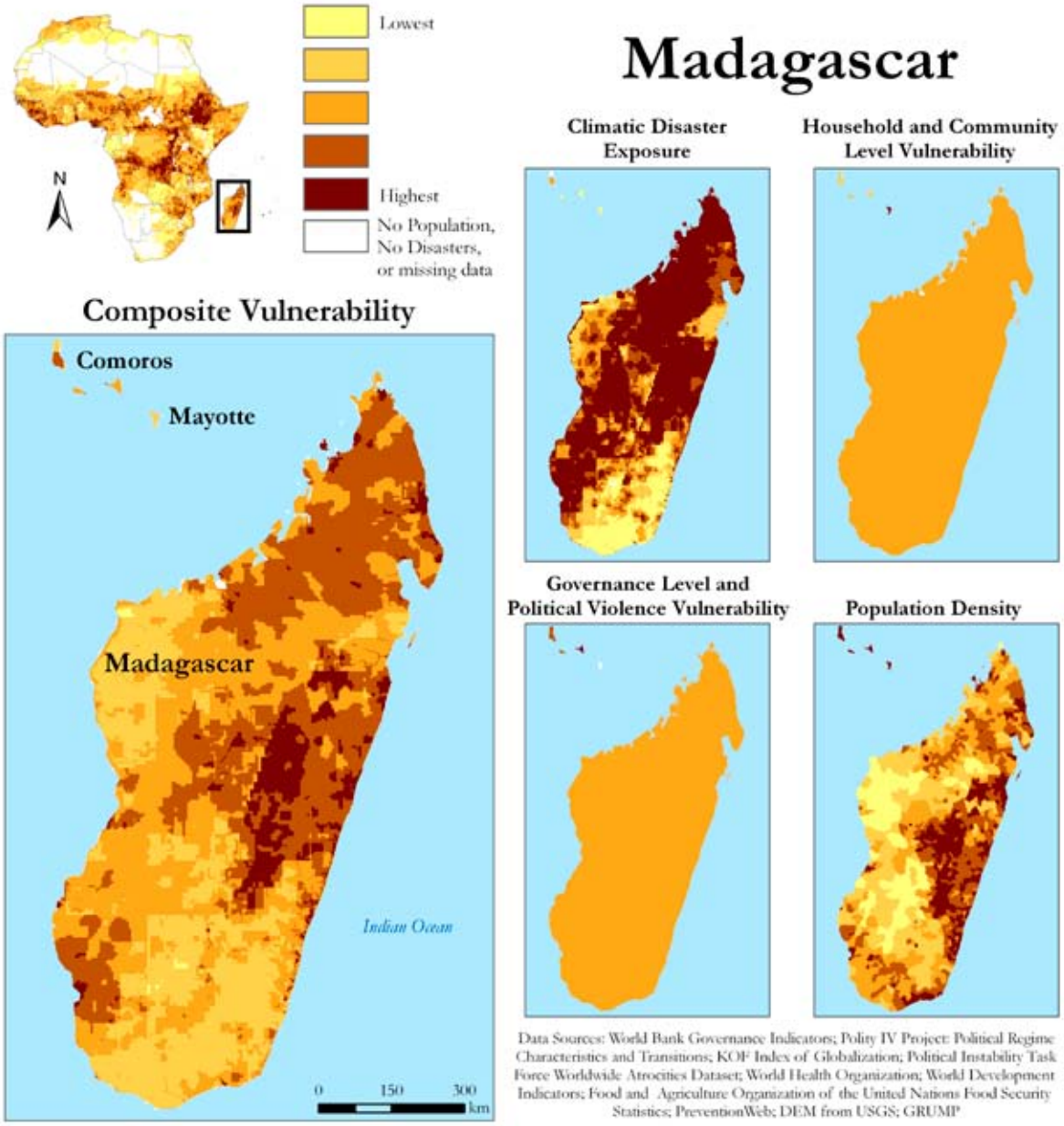


FIGURE 6

to low-elevation coastal zone exposure and wildfires. However, high population density, household and community level vulnerability, governance vulnerability, and politically motivated violence also contribute to overall vulnerability in this region (see Figure 7). In these areas, effective adaptation efforts may include severe weather early warning systems, sea walls, and improved building codes, though these alone are unlikely to be effective without addressing broader governance challenges.

The Niger delta region of Nigeria—Port Harcourt and surrounding area—is a prime example of the confluence between high

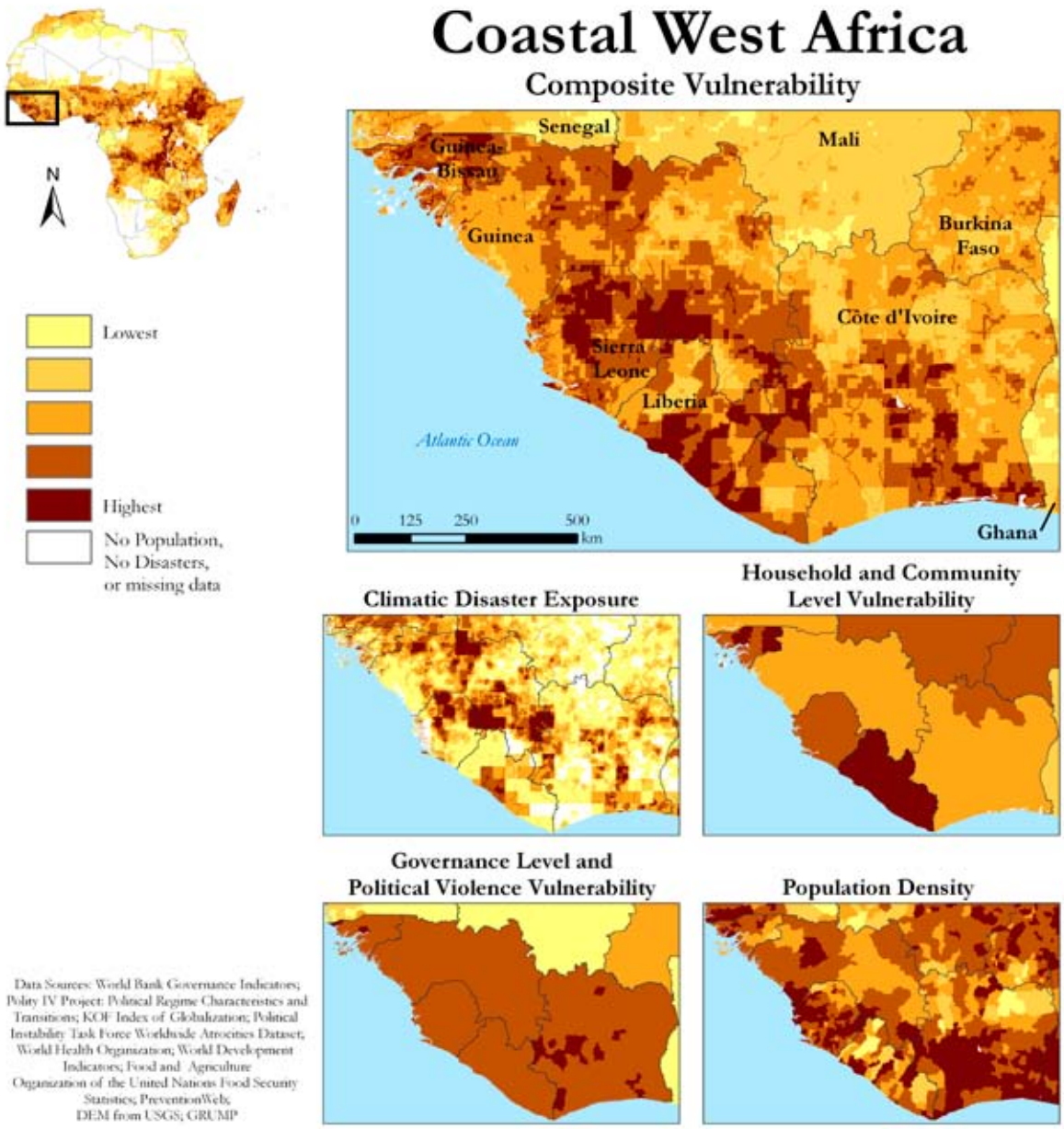


FIGURE 7

population density and high physical exposure to natural disasters, primarily flooding and coastal inundation (see Figure 8). On household and community vulnerability as well as governance, Nigeria ranked near the middle. In neither case was this moderate national vulnerability able to compensate for the high vulnerability of Nigeria's dense population that lives along the coast. With its oil refineries, periodic violence by armed militia groups, and history of secessionist movements, Nigeria's coast, particularly Rivers State, is of special concern. In these areas of interrelated vulnerabilities, effective interventions are much more difficult to design, but will necessarily need to

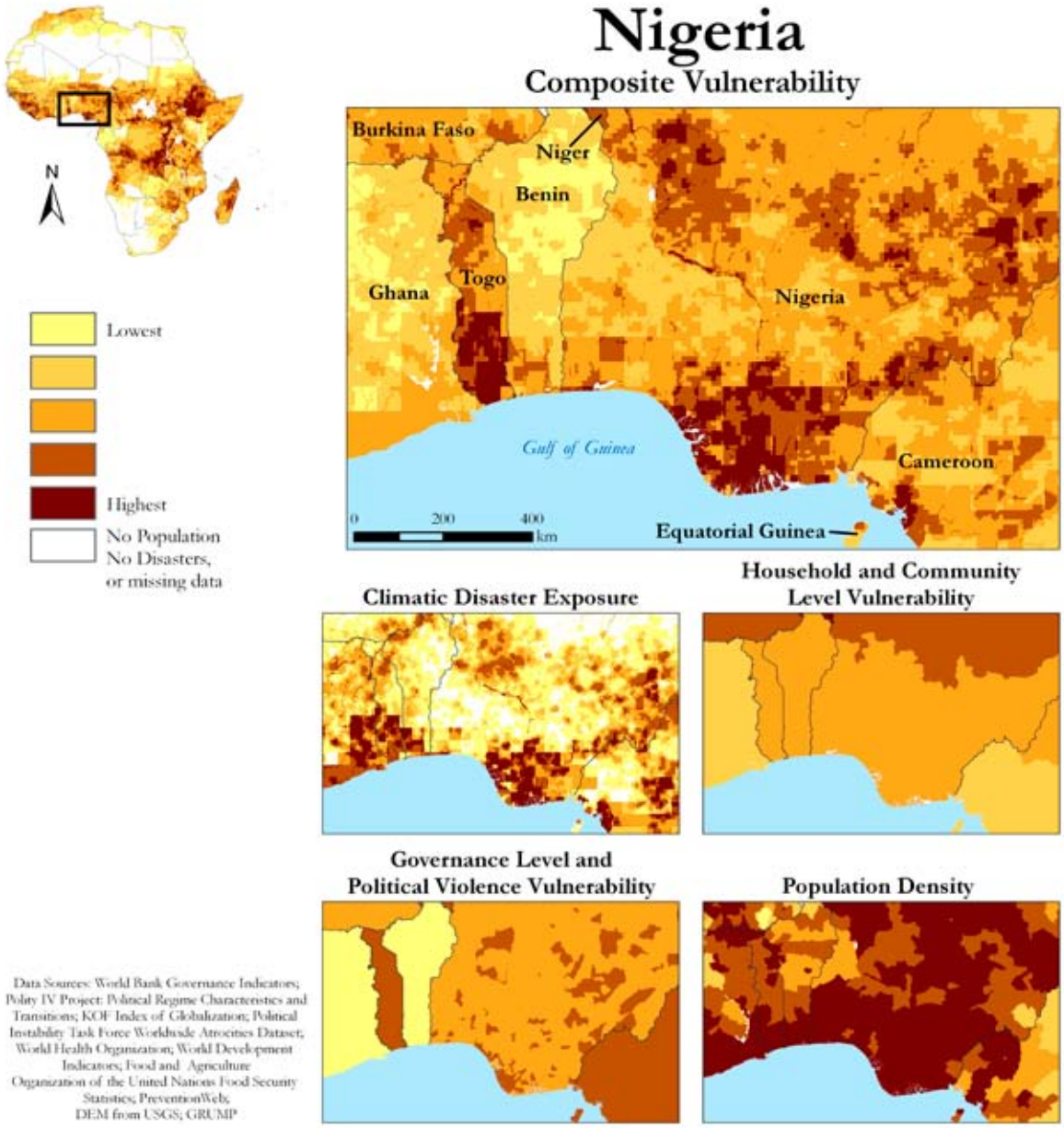


FIGURE 8

address not just the physical exposure risks, but also risks of governance vulnerability and violence.

In other areas, the vulnerability to future climate change is the consequence of past events. First, with a population of approximately 81 million, Ethiopia is the third most populous nation in Africa, behind Nigeria and Egypt. As shown in the Figure 9, much of this population is concentrated in the drought-prone western half of the country where a lack of irrigation infrastructure means the population is largely reliant on rain-fed agriculture. These factors contributed to severe famines in the past

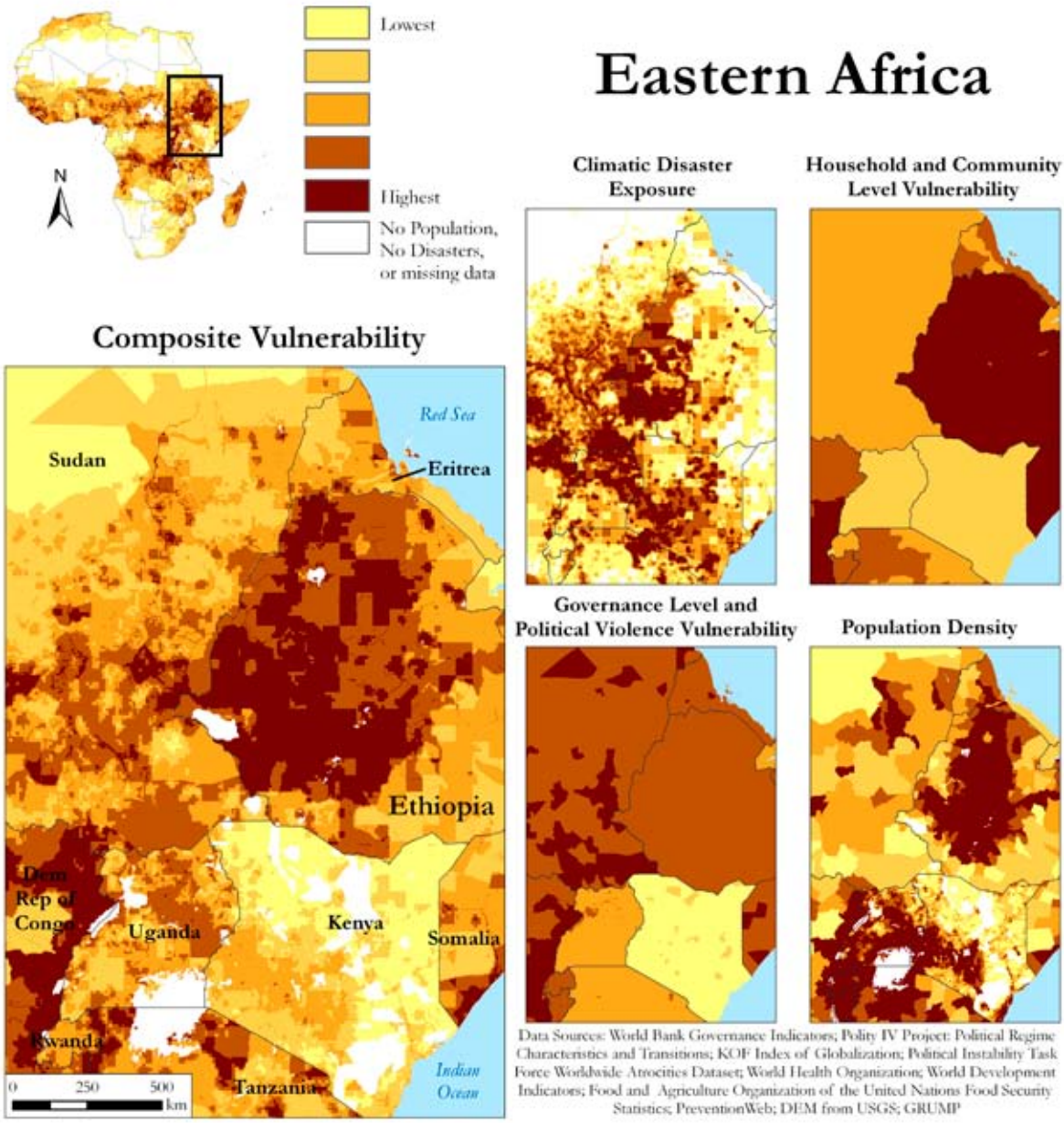


FIGURE 9

several decades that have, in turn, led to the country's poor nutritional and health status today. Finally, although Ethiopia has seen relatively little political violence compared to its neighbors, the government scores poorly on the World Bank's voice and accountability index and has limited capacity to respond to disasters or adapt to changing conditions. Here programs to develop irrigation infrastructure and promote drought resistant crops could be pivotal, but there is little hope for such programs without improved governance.

A second example of a region more vulnerable to future climate change due

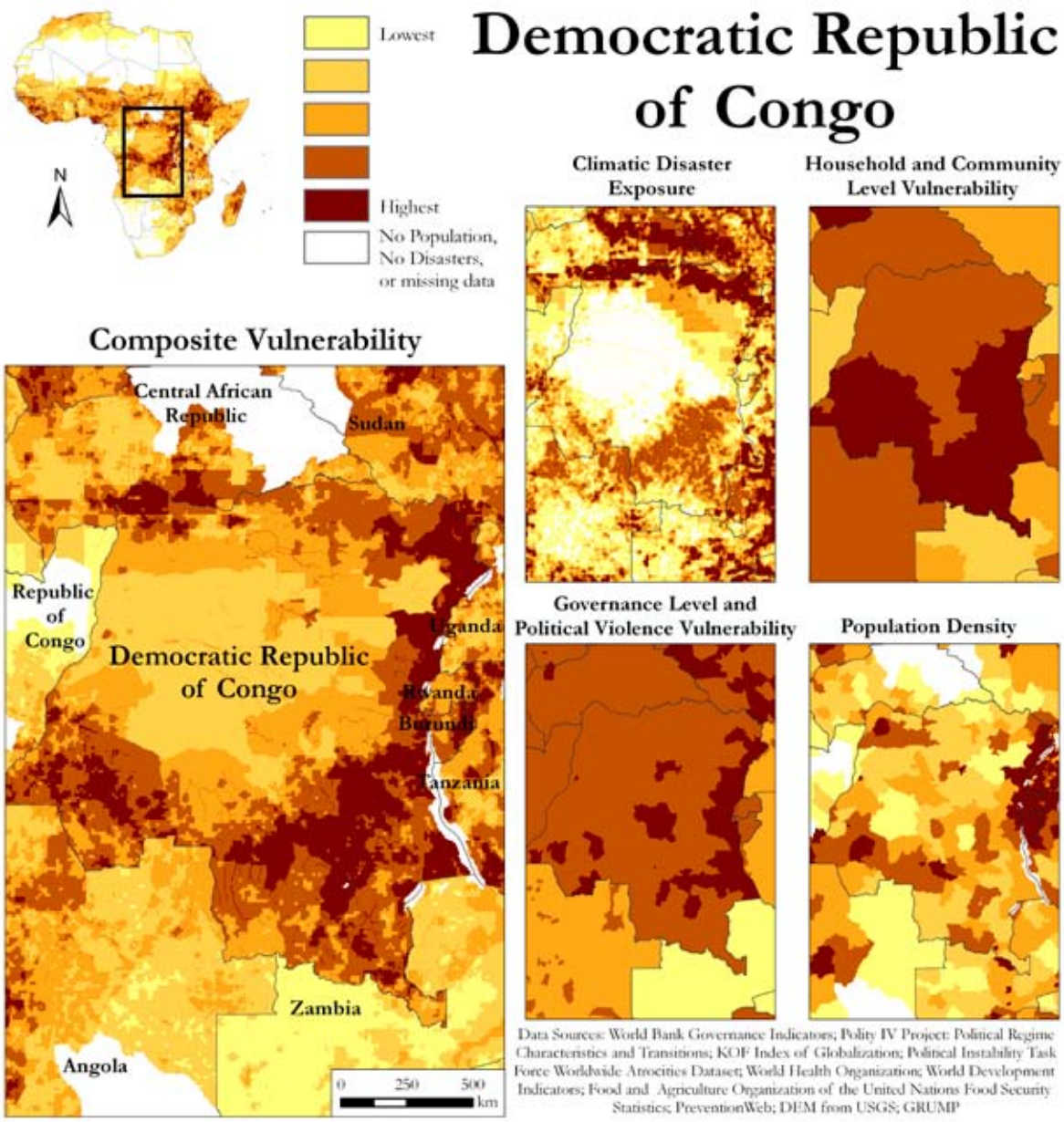


FIGURE 10

to past events is the eastern half of the Democratic Republic of Congo, which shows up as vulnerable for different reasons (see Figure 10). With the exception of the droughts in the far north of the country and wildfires in the far north and far south, DRC is less exposed to natural disasters than other parts of Africa. However, poor governance throughout DRC gives it the second lowest score on this study's Governance Vulnerability index. Ongoing political violence, particularly in the east, is related to the war that officially ended in 2003 but continues to plague much of the region. This has hampered development and the population's ability to adapt to changing environmental conditions. Furthermore, continuing violence undermines efforts by the government and international actors to respond to natural or humanitarian disasters.

Although effective interventions will need to address many drivers of vulnerability, governance improvement is paramount. More accountable, responsive, and capable governments are integral to reducing household and community vulnerability, adapting to changing environmental conditions, and responding to inevitable natural disasters.

One danger of this comparative approach is that it has the potential to focus attention on larger regions of vulnerability at the expense of smaller areas. Although not explicitly discussed, other pockets of high vulnerability exist in Tanzania, Zimbabwe, Rwanda, Swaziland, and Mozambique, where low scores on human development coincide with poor governance indicators and considerable disaster risk from droughts and fires. These areas must not be overlooked.

Conclusions and Extensions for Further Research

This paper is intended to be a proof of concept for a methodology of producing sub-national climate change vulnerability maps. The aim is to be holistic if not exhaustive in the inclusion of variables. For a number of indicators, particularly those for household vulnerability and governance, researchers had to use national level data in the absence of local geo-referenced data. As a consequence, the location of sub-national vulnerability is as not as precise as it ultimately can be. While some indicators—such as disasters, low elevation, population, and atrocities—are geo-referenced at the sub-national level, better data is required for many others. Subsequent iterations of this model will attempt to acquire more localized data for included indicators.

The researchers ultimately hope to also include data on infrastructure. In the event of a weather emergency, communities at risk will often need emergency services in the form of search and rescue, relief supplies, and reconstruction materials. Communities that are isolated from transportation and information networks may be more at risk, as it may be difficult to warn them of impending disasters and provide them

adequate services in the event of climate-related disasters. While access to communications infrastructure may be more applicable for swift onset disasters like floods and storms, access to transportation infrastructure could be potentially salient for slow onset disasters, such as droughts. The team ultimately intends to include two indicators to track relative isolation from relief services, focusing on the size of populations isolated from roads and airports. Other measures that capture the relative isolation of a population from communications infrastructure may ultimately be included, including access to radios. However, some existing data sources may not be appropriate. For example, the primary roads data for South Africa from Digital Chart of the World does not include some of the major paved roads along the southern coast. This dataset may not be able to capture the underlying issue of interest—the relative isolation of people from the road network—particularly if the classification for secondary roads includes paved highways in one country but only dirt tracks in another.

The research team would also be interested to include data on agriculture and primary commodities, in terms of the significance for the local economy and for export revenues. Economies highly dependent on agriculture and the export of primary commodities are likely to be especially affected as the effects of climate change impact the food supply. Given Africa's dependence on rain-fed agriculture, its low levels of industrialization and manufacturing, and its particular susceptibility to drought, the inclusion of such indicators will likely be important to assessing countries' overall vulnerability to climate change.

In addition, most of the physical vulnerability data in this paper is based on past disaster frequencies and intensities. The next iteration of research will incorporate models of future climate change risk, to the extent that authoritative models of future climate trends in Africa can be found. Indeed, models of future African climate change, at least for some areas like the Sahel, appear to have wildly divergent predictions with respect to rainfall and other indicators.[62] More recent research, however, suggests these discordant findings may be a product of problems in downscaling global climate models. Patricola and Cook have constructed a regional climate model for north Africa above the equator (and excluding typical north African countries on the Mediterranean coast).[63] They argue that their findings are much more consistent than previous climate prediction models and have more success in explaining past climate patterns and important attributes like the West African monsoon. For future research, the team conducting this climate vulnerability study is collaborating with climate modelers including Kerry Cook to extend the regional model to be continent-wide and to focus on time scales relevant for policymakers—mid-21st century—rather than late 21st century as is the norm among climate modelers.

Maps of vulnerability are only points of departure rather than end-states of analysis.

Additionally, the consequences of climate-related disasters may be more severe in regions with a history of political violence, as both conflict and weather events can spill over borders. Dealing with climate change effects in violent regions may be problematic, in terms of eliciting cross-border cooperation and the damage wrought to governance and development in areas plagued by perennial conflict. The neighborhood effects of political violence may be included in subsequent iterations, as well as indicators other than the political atrocities data to capture more large-scale violence such as civil wars. The ACLED dataset, as well as Halvard Buhaug's geo-referenced work on African civil wars, are prospective data sources for these extensions.[64] Ultimately, the models will also incorporate geo-coded strike and riot event data from Idean Salehyan and Cullen Hendrix's new dataset, which point to civil unrest.[65]

For future work, a variety of sensitivity analyses will also be conducted. For example, each of the four baskets is currently weighted equally in the index. If the weight attached to population is reduced, for example, more extensive areas fall in to the most vulnerable quintile. A variety of sensitivity tests like this can demonstrate how the overall patterns of vulnerability change with different weights. Areas that are continually found to be vulnerable across different model specifications will be noted. Similar analyses can be performed to assess country-level drivers of vulnerability. For example, in extensions of the work, altering the values for individual indicators for particular countries can show what effect an improvement on a particular sub-indicator would have on the country's overall vulnerability rating. Such a move could in turn help identify appropriate policy interventions that could ostensibly reduce country vulnerability to climate change. For example, if improving a country's caloric intake would significantly improve its household vulnerability score—and, in turn, its overall vulnerability ranking—policy interventions to improve food security and income could receive priority.

Changing how vulnerability indicators are classified is another possible extension of the methodology in this study. This study uses quintiles to classify the vulnerability scores for each basket and for the final composite vulnerability map. This method results in the total geographic area in each of the five classifications being roughly equal. There may be other classification methods that could be justified over quintiles, such as natural breaks. It may be appropriate to

use different classification methods for different baskets.

An additional extension would be to overlay geo-coded data on ethnicity. Given that ethnicity has appeared to play a strong role in African politic— as a source of conflict and division—ethnicity could play a powerful role in determining future vulnerability to the effects of climate change as well. In some cases, ethnic groups may be actively targeted by the government such that, in the event of an extreme weather event, ethnic groups at odds with the government may be deprived of essential relief services. In other cases, powerless and politically irrelevant groups may be ignored by the central government, should they find themselves subject to extreme weather events or other effects associated with climate change. A geo-coded version of the Ethnic Power Relations (GeoEPR) dataset was recently published.[66] This data could help identify where vulnerable areas overlap with ethnic groups that have experienced historic discrimination, that are powerless, or that are politically irrelevant.[67]

A further extension would be to statistically test the strength of the indicators as predictors of outcomes such as disaster mortality, as Roberts and Parks have done using multivariate regression and Brooks et al. did using Monte Carlo simulations. These can be done for multiple hazards or for individual hazards. For example, the 2009 UNISDR global assessment on disasters assesses the statistical significance of different factors to individual kinds of disasters. Consistent with the Brooks et al. study, UNISDR includes a number of different variables, including per capita net savings, ratio of economic losses to the capital stock, economic competitiveness, concentration of exports, the Human Development Index, and per capita GDP.[68] It is also possible to conduct geographically weighted regression within ArcGIS, which may be possible with the findings of this study in the future.

Maps of vulnerability are only points of departure rather than end-states of analysis. Having provisionally identified the places of greatest sub-national vulnerability within Africa, the research team needs to understand more about the historical and political dynamics of those places and how such dynamics intersect with historical climate-related disasters and climate change. The research team will use case studies and field work to complement the maps developed thus far.

The more holistic approach to vulnerability analysis outlined in this study can provide strong guidance to policymakers within Africa and internationally as they work to identify the most vulnerable regions at the most detailed scale possible in Africa. It is the hope of this research team that identifying refined geographic areas of interest can help policymakers tailor adaptation strategies and distribute scarce resources to the places in Africa where the need is greatest.

APPENDICES

Appendix A: Countries Most Vulnerable to Disasters, 1968-2007, Raleigh and Jordan

Droughts	Floods	Windstorms
Burkina Faso, Mozambique, Rwanda, Somalia, Tanzania	Afghanistan, Bangladesh, Malawi, Mozambique, Nepal, Nigeria, Somalia, Sudan, Tanzania	Bangladesh, Madagascar, Mozambique

Appendix B: Countries Most Vulnerable to Climate and Political Risks, Levy et al.[69]

Coastal Population Exposure		Aggregate Temperature Changes	Water Scarcity
Based on Population Exposed	Based on Percentage of Population		
China, Philippines, India, Indonesia	Philippines, Egypt, Indonesia	South Africa, Nepal, Morocco, Bangladesh, Tunisia, Paraguay, Yemen, Sudan, Côte d'Ivoire	Mozambique, Côte d'Ivoire, Nigeria, Iraq, Guatemala, Zimbabwe, Ethiopia, Somalia, China, Syria, Algeria

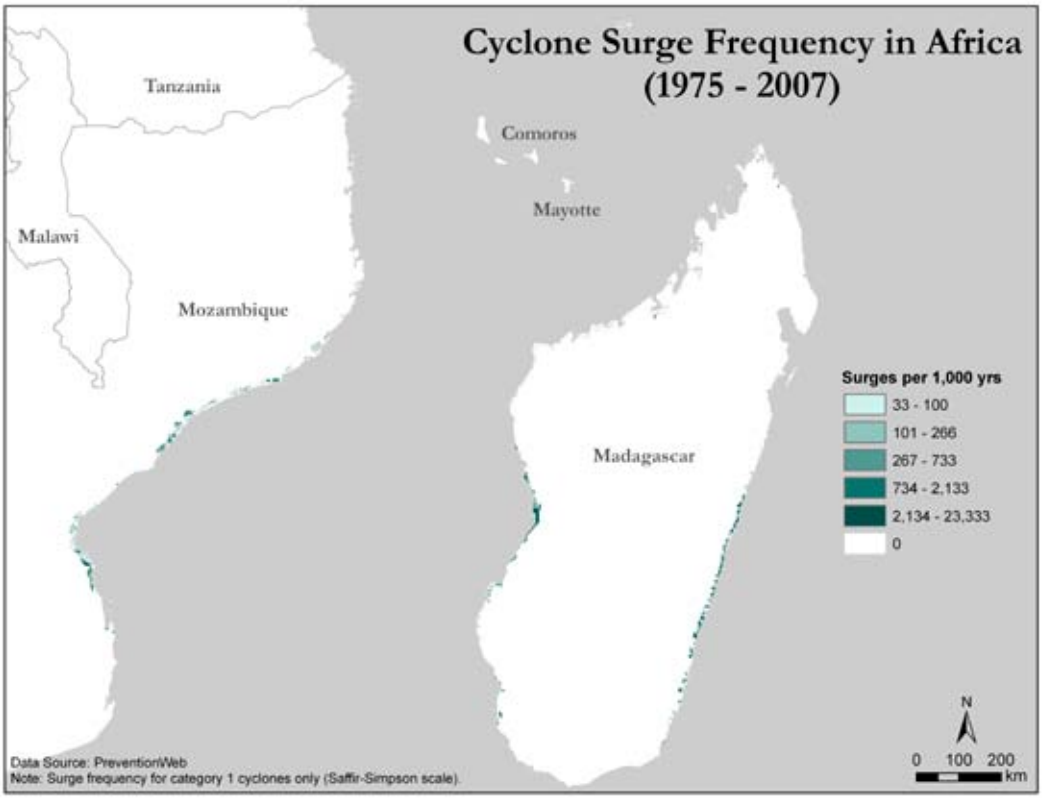
Appendix C: Countries Most Vulnerable to Climate Change and Disaster Mortality, Brooks et al.[70]

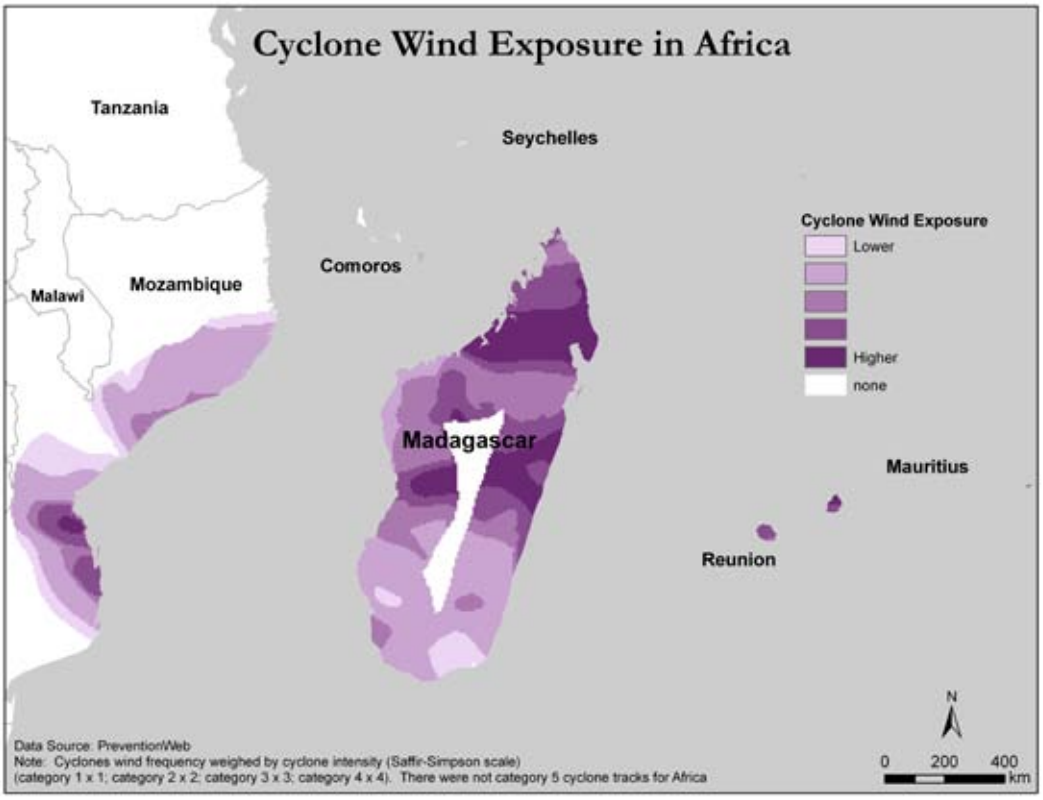
Afghanistan
Angola
Burundi
Central African Republic
Democratic Republic of Congo
Eritrea
Ethiopia
Equatorial Guinea
Gambia
Guinea Bissau
Haiti
Mauritania
Mozambique
Niger
Pakistan
Rwanda
Sierra Leone
Somalia
Sudan
Togo

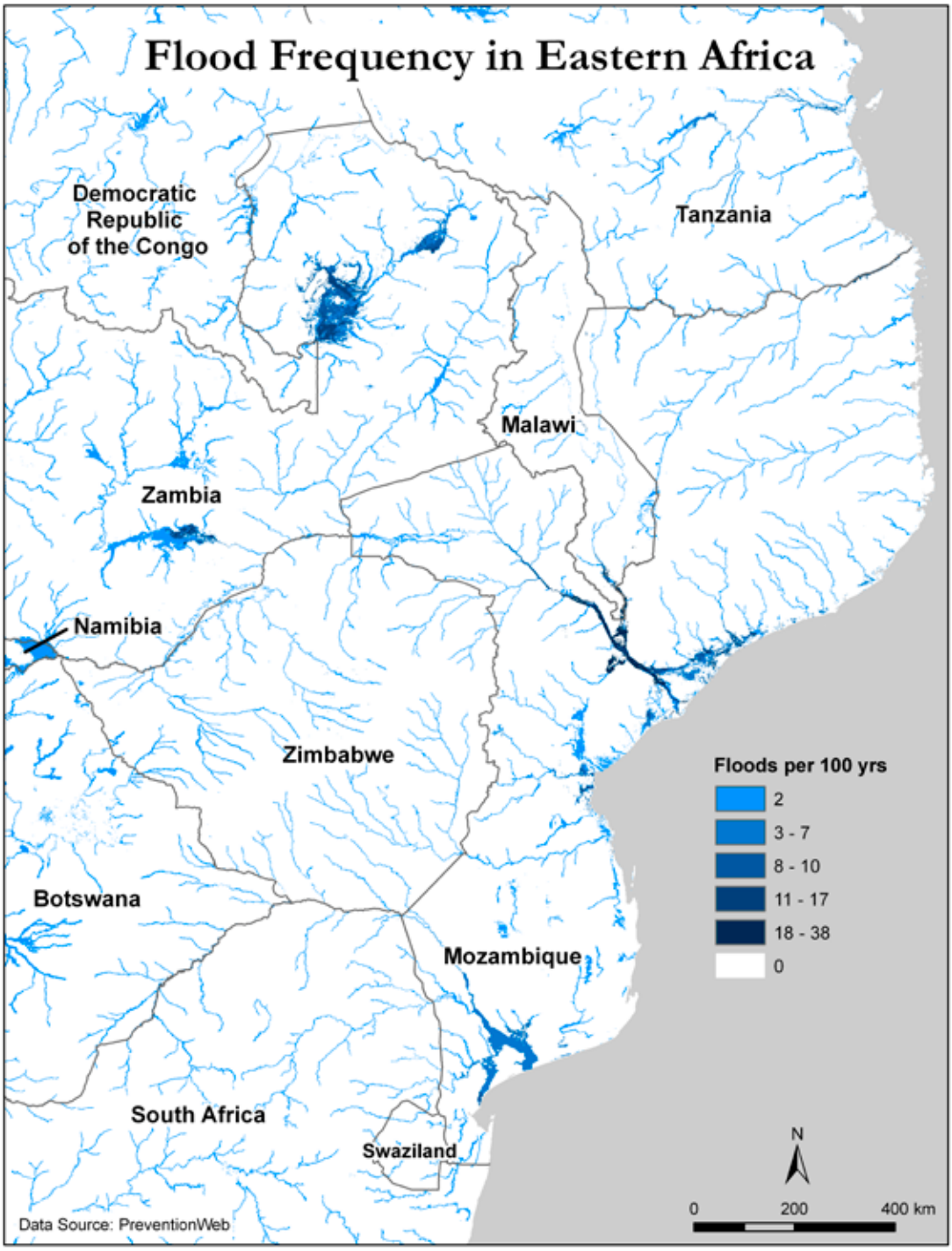
Appendix D: Top Tertile of 102 Vulnerable Countries, Brenkert and Malone

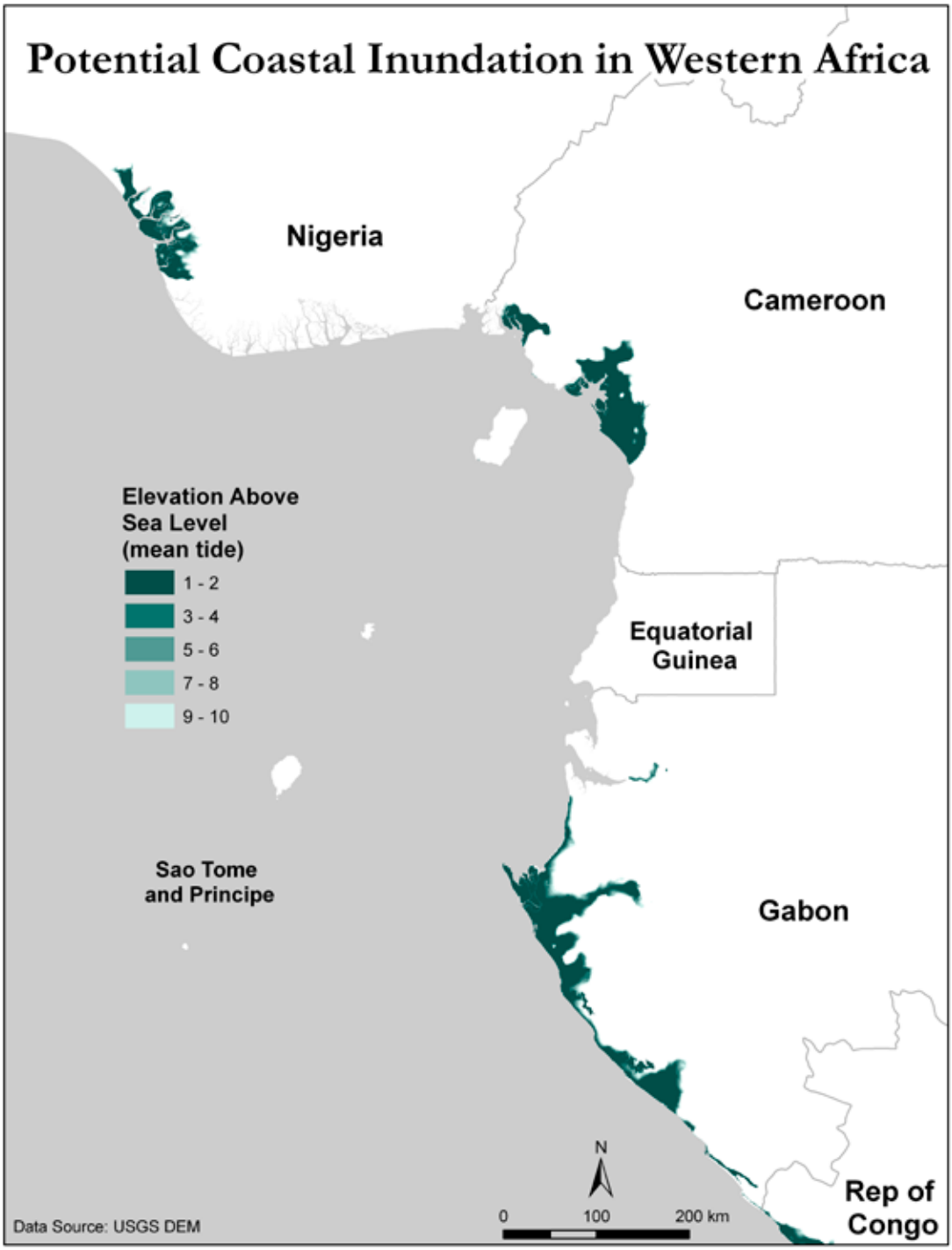
Sierra Leone
Bangladesh
Somalia
Mozambique
Ethiopia
Rwanda
Benin
Yemen
Angola
Kenya
Senegal
Nigeria
Uganda
Madagascar
Sudan
Nepal
Haiti
Guatemala
Syria
Kuwait
Swaziland
Zimbabwe
Pakistan
South Africa
Ghana
Nicaragua
India
Congo
Morocco
Honduras
El Salvador
Cameroon
Dominican Republic

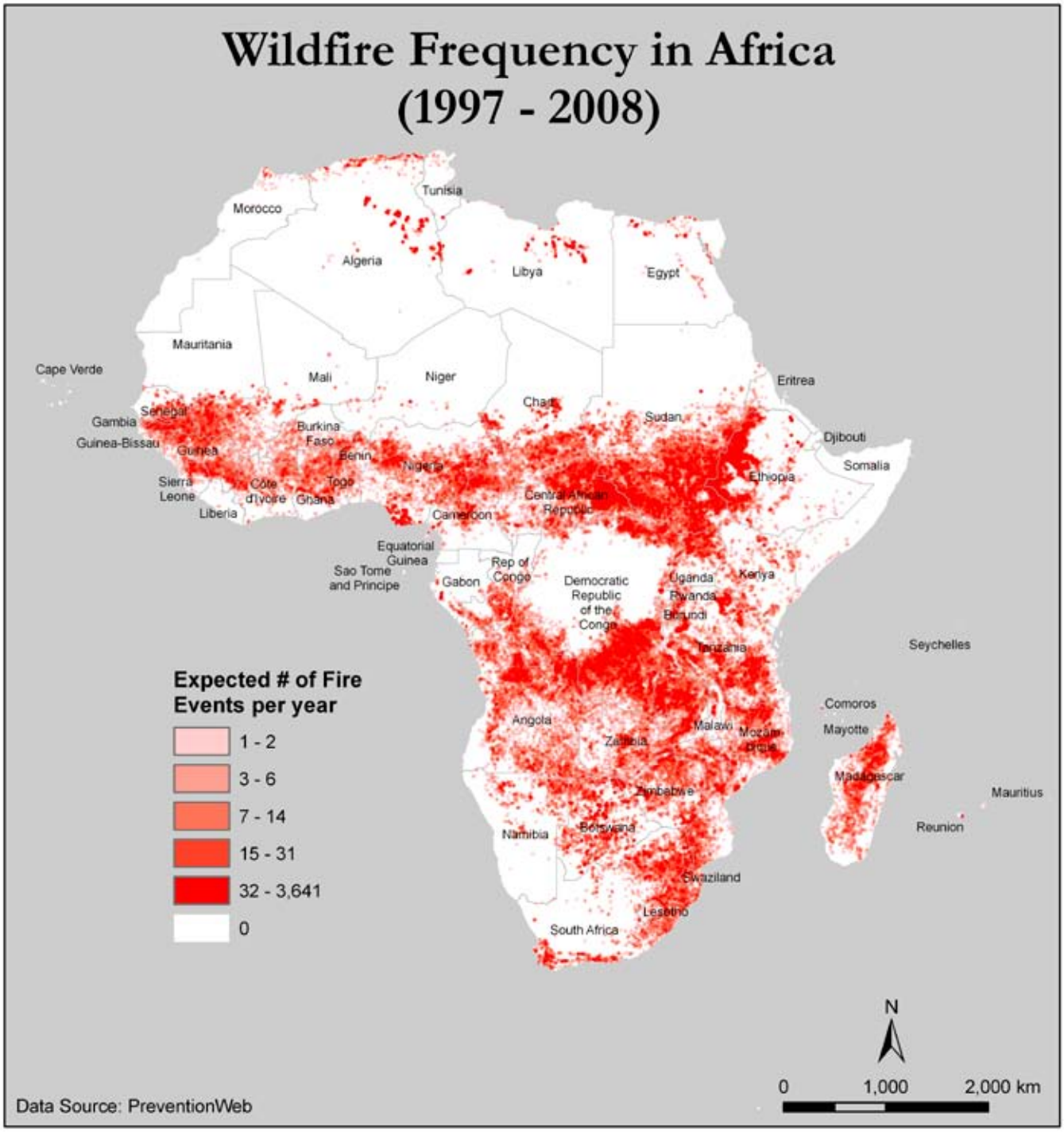
Appendix E: Indicators of Climate-Related Disaster Exposure

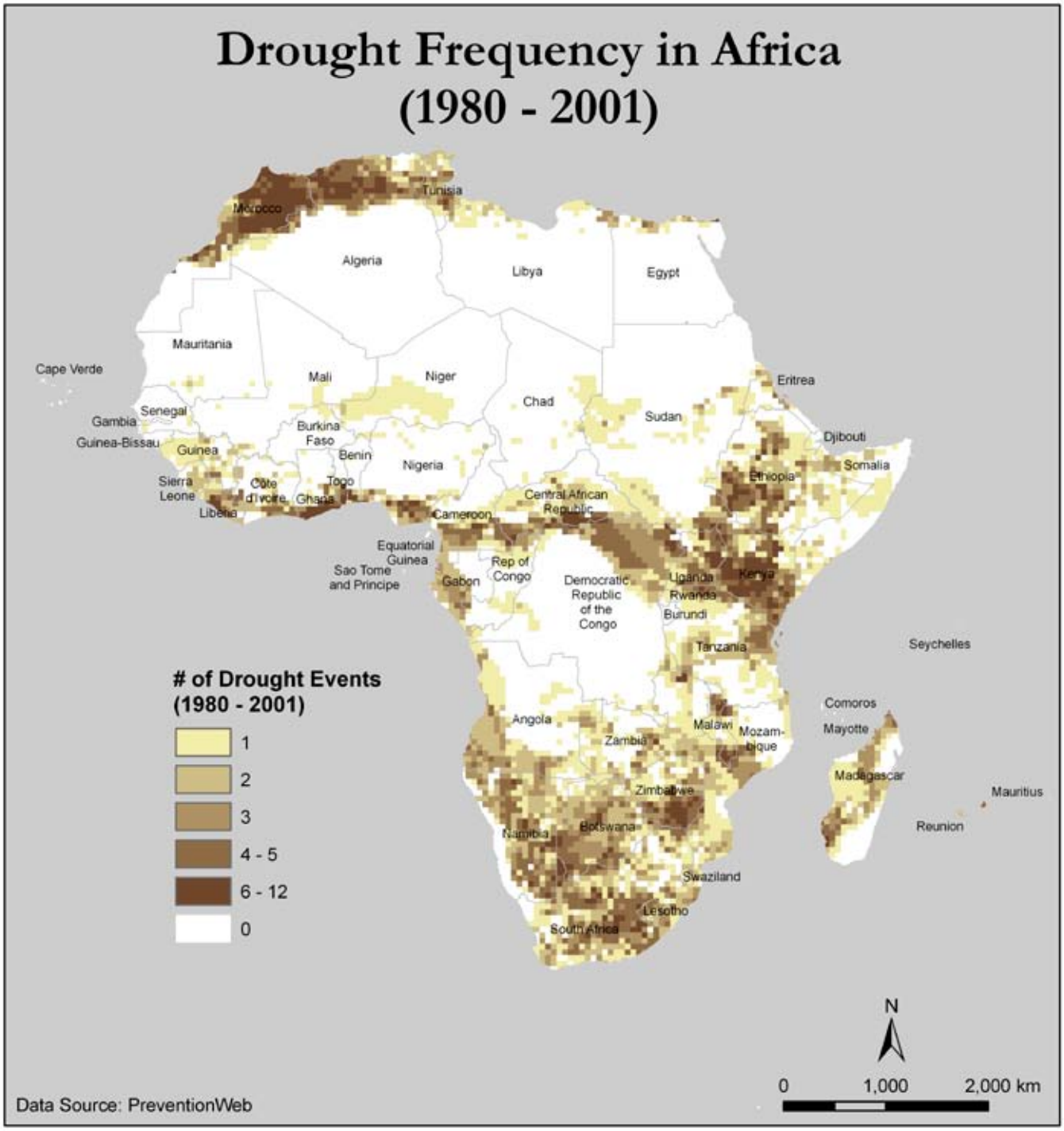




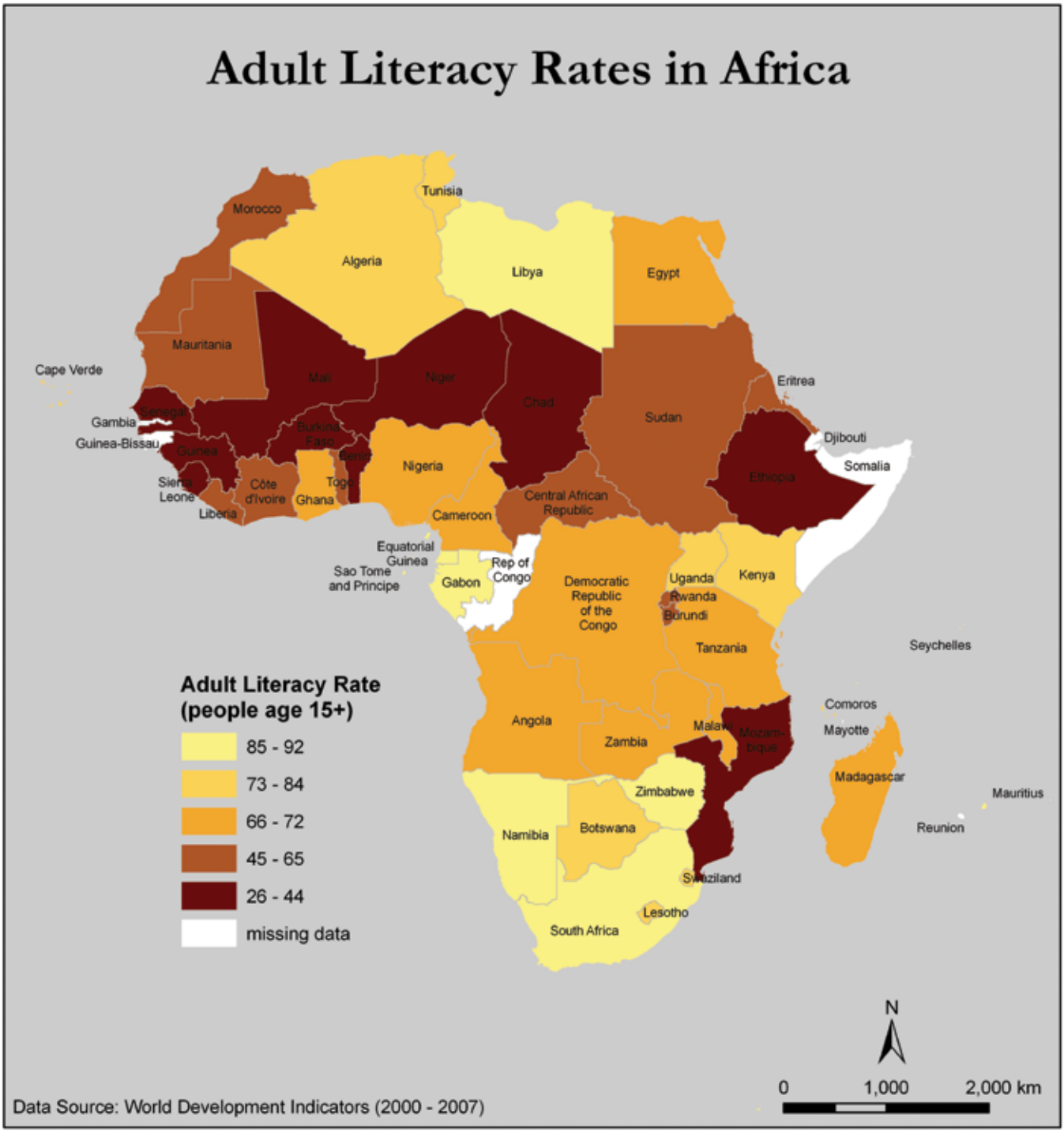

Flood Frequency in Eastern Africa
Democratic Republic of the Congo
Tanzania
Malawi
Zambia
Namibia
Zimbabwe
Botswana
Mozambique
South Africa
Swaziland
Floods per 100 yrs
2
3 - 7
8 - 10
11 - 17
18 - 38
0
N
0
200
400 km
Data Source: PreventionWeb

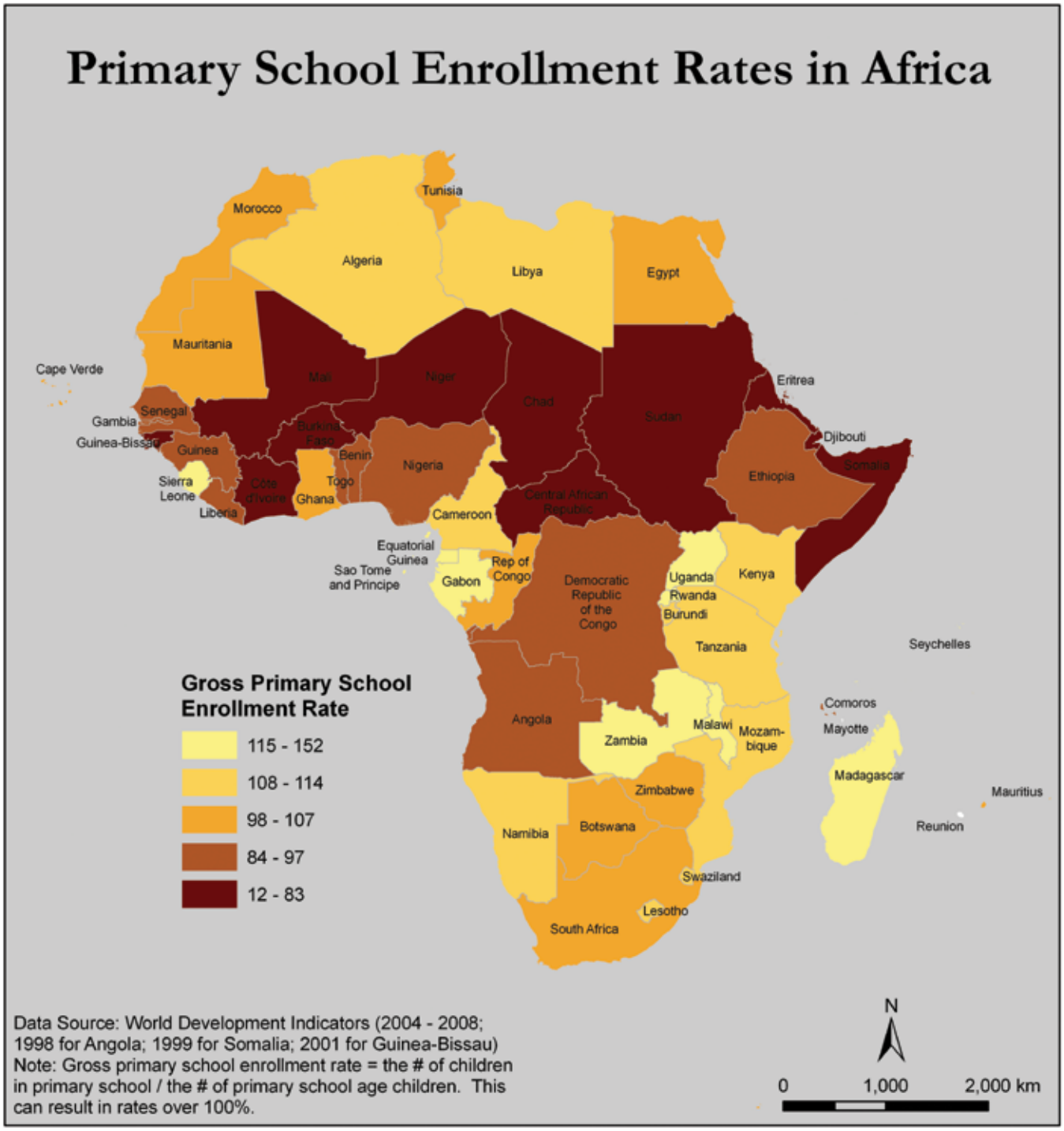

Potential Coastal Inundation in Western Africa
Nigeria
Cameroon
Elevation Above
Sea Level
(mean tide)
1 - 2
3 - 4
5 - 6
7 - 8
9 - 10
Equatorial
Guinea
Sao Tome
and Principe
Gabon
Rep of
Congo
N
0
100
200 km
Data Source: USGS DEM


Wildfire Frequency in Africa
(1997 - 2008)
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Eritrea
Chad
Sudan
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozambique
Madagascar
Zimbabwe
Mauritius
Reunion
Namibia
Botswana
Swaziland
Lesotho
South Africa
Expected # of Fire Events per year
1 - 2
3 - 6
7 - 14
15 - 31
32 - 3,641
0
N
0
1,000
2,000 km
Data Source: PreventionWeb

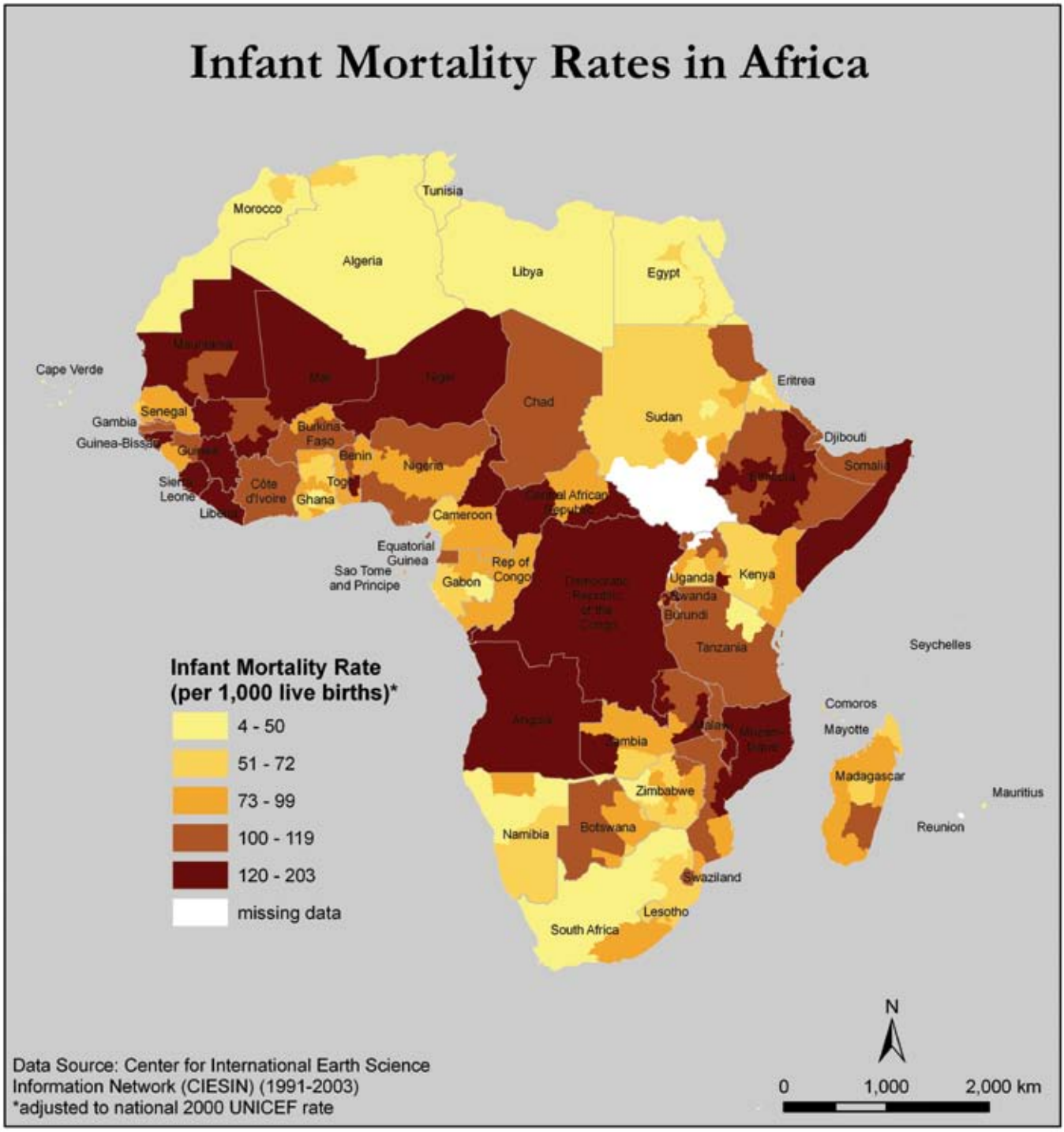

Drought Frequency in Africa
(1980 - 2001)
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Somalia
Ethiopia
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Cameroon
Central African Republic
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Madagascar
Mauritius
Reunion
Angola
Zambia
Malawi
Mozambique
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
# of Drought Events
(1980 - 2001)
1
2
3
4 - 5
6 - 12
0
N
0
1,000
2,000 km
Data Source: PreventionWeb

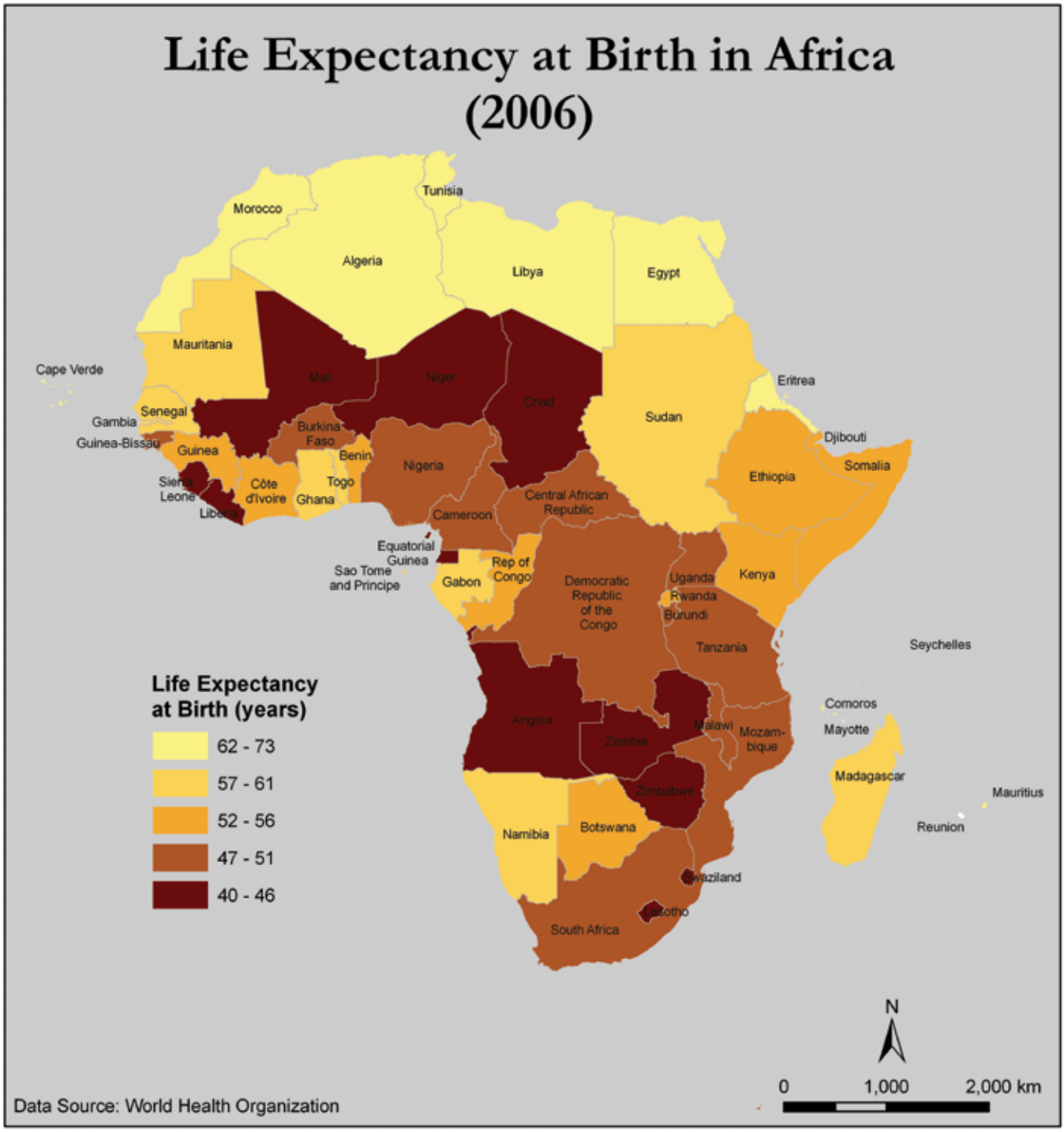
Appendix F: Indicators of Household and Community Level Vulnerability

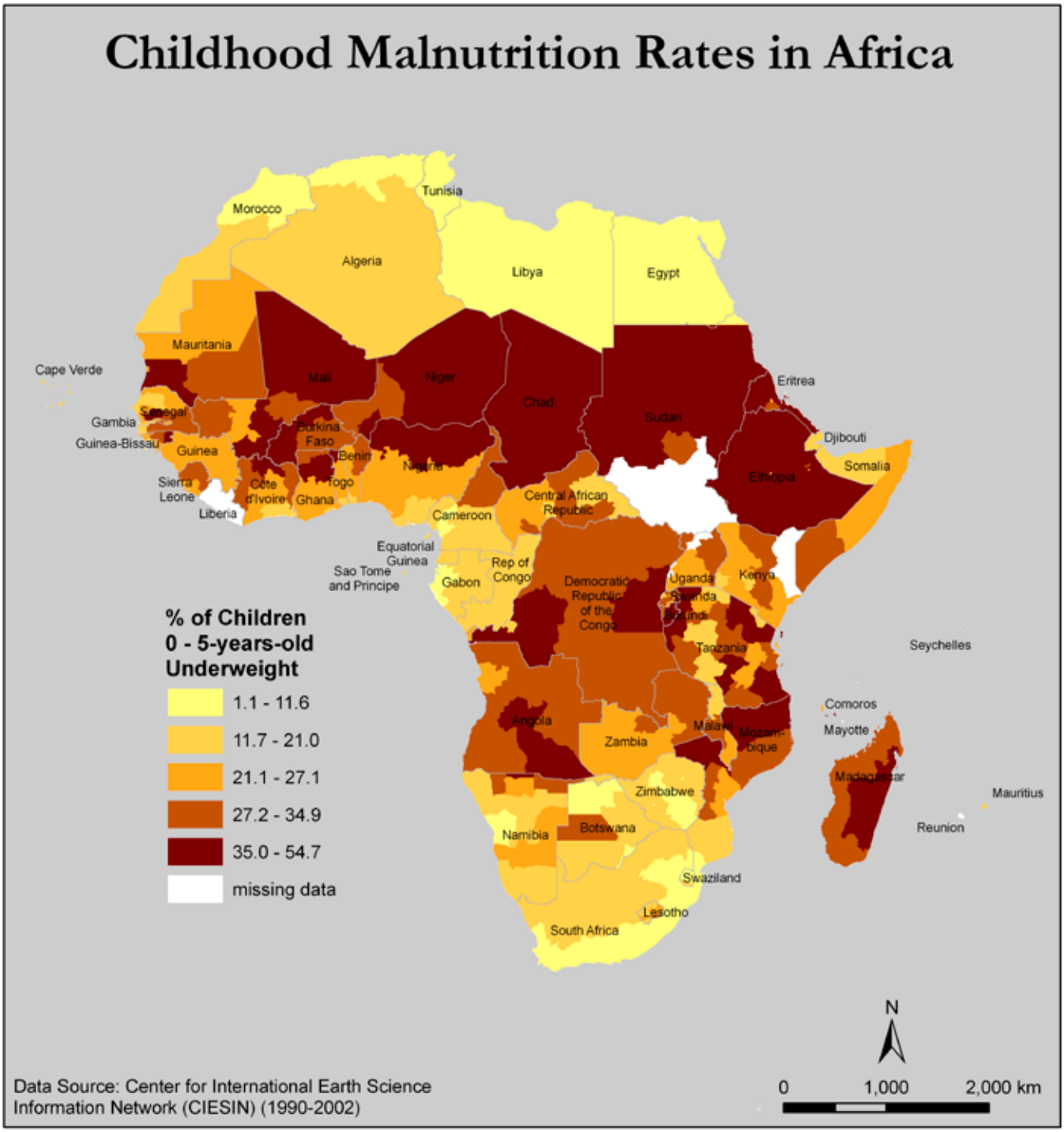


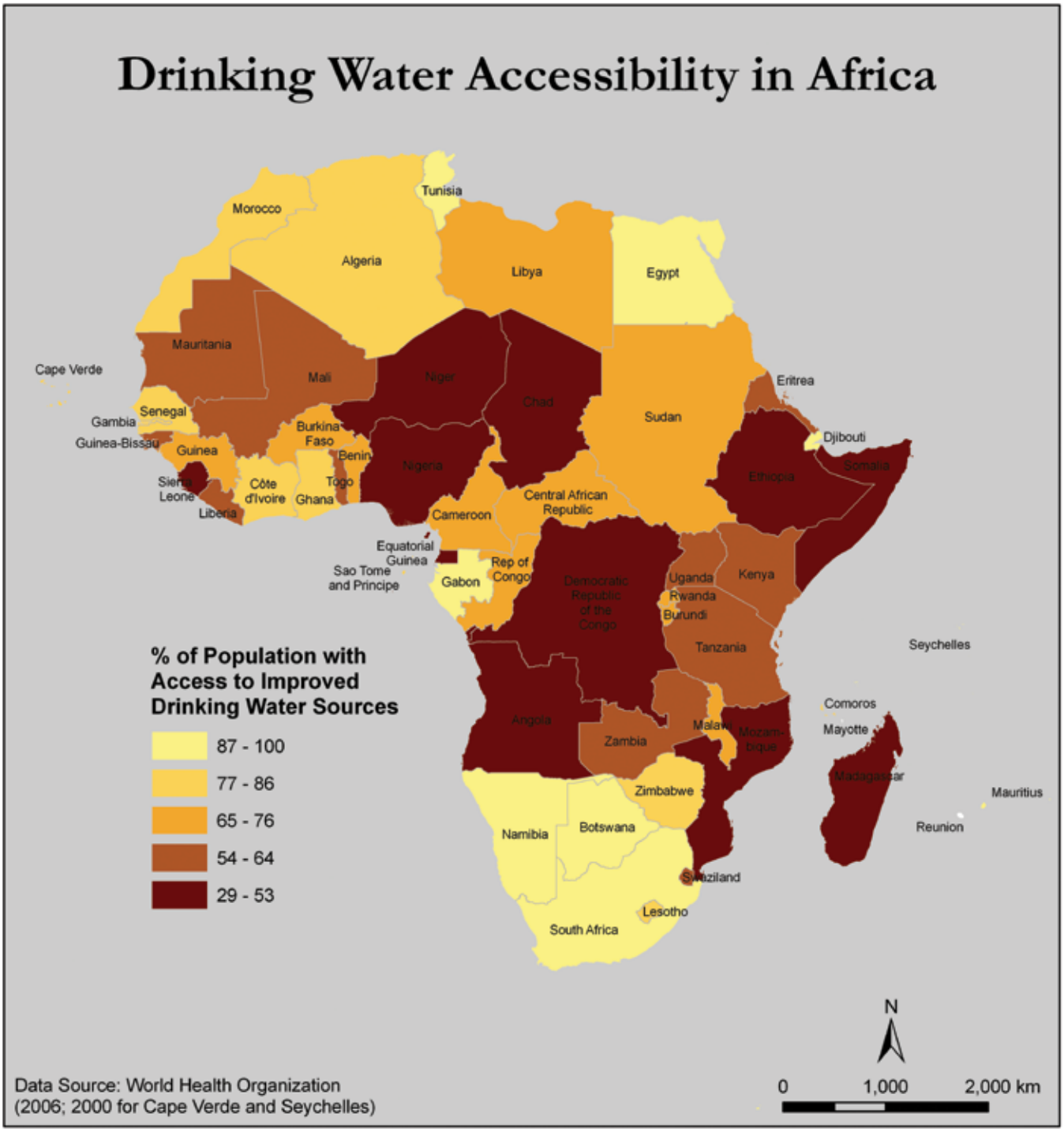


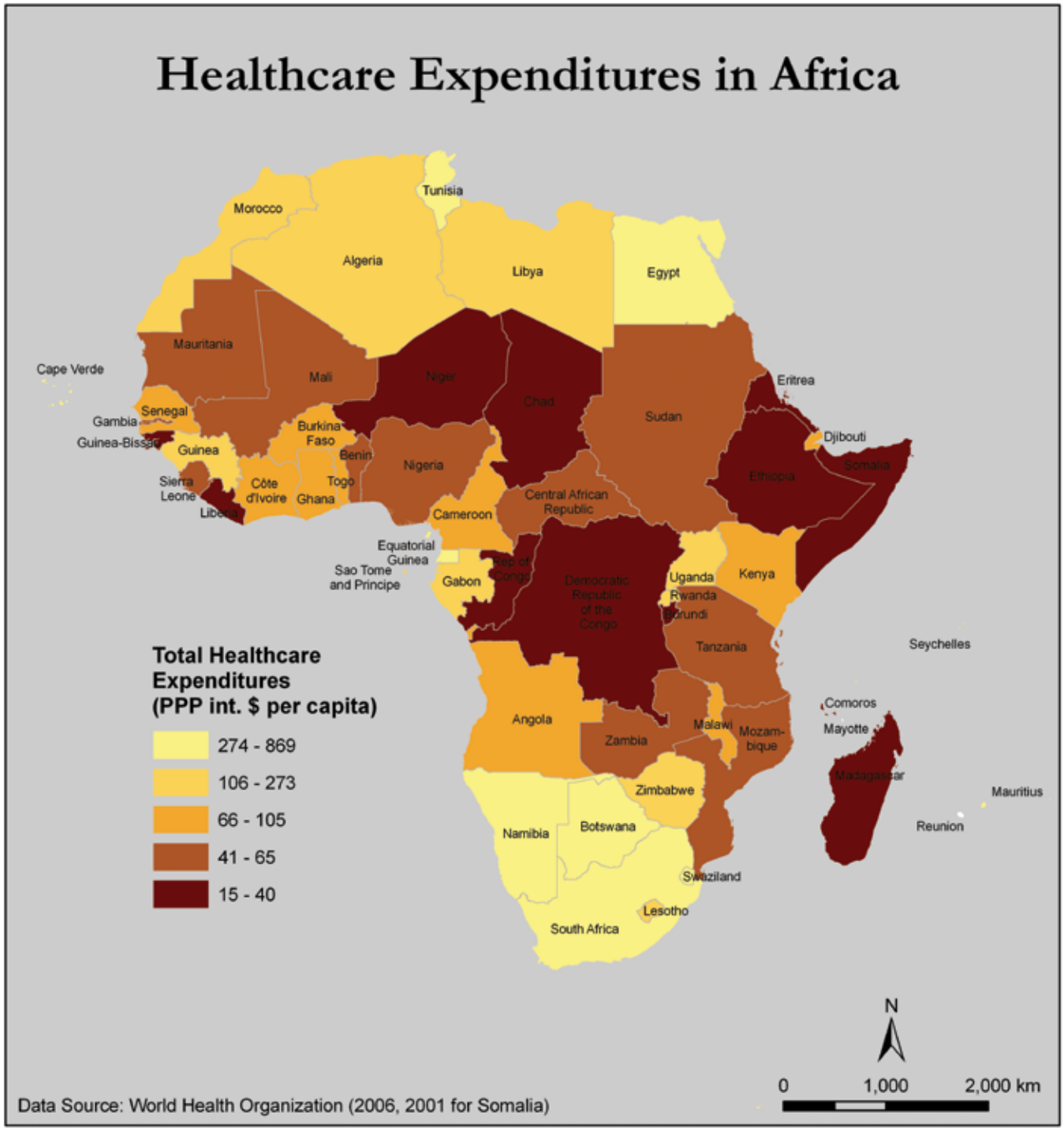
Data Source: World Development Indicators (2004 - 2008; 1998 for Angola; 1999 for Somalia; 2001 for Guinea-Bissau)
Note: Gross primary school enrollment rate = the # of children in primary school / the # of primary school age children. This can result in rates over 100%.

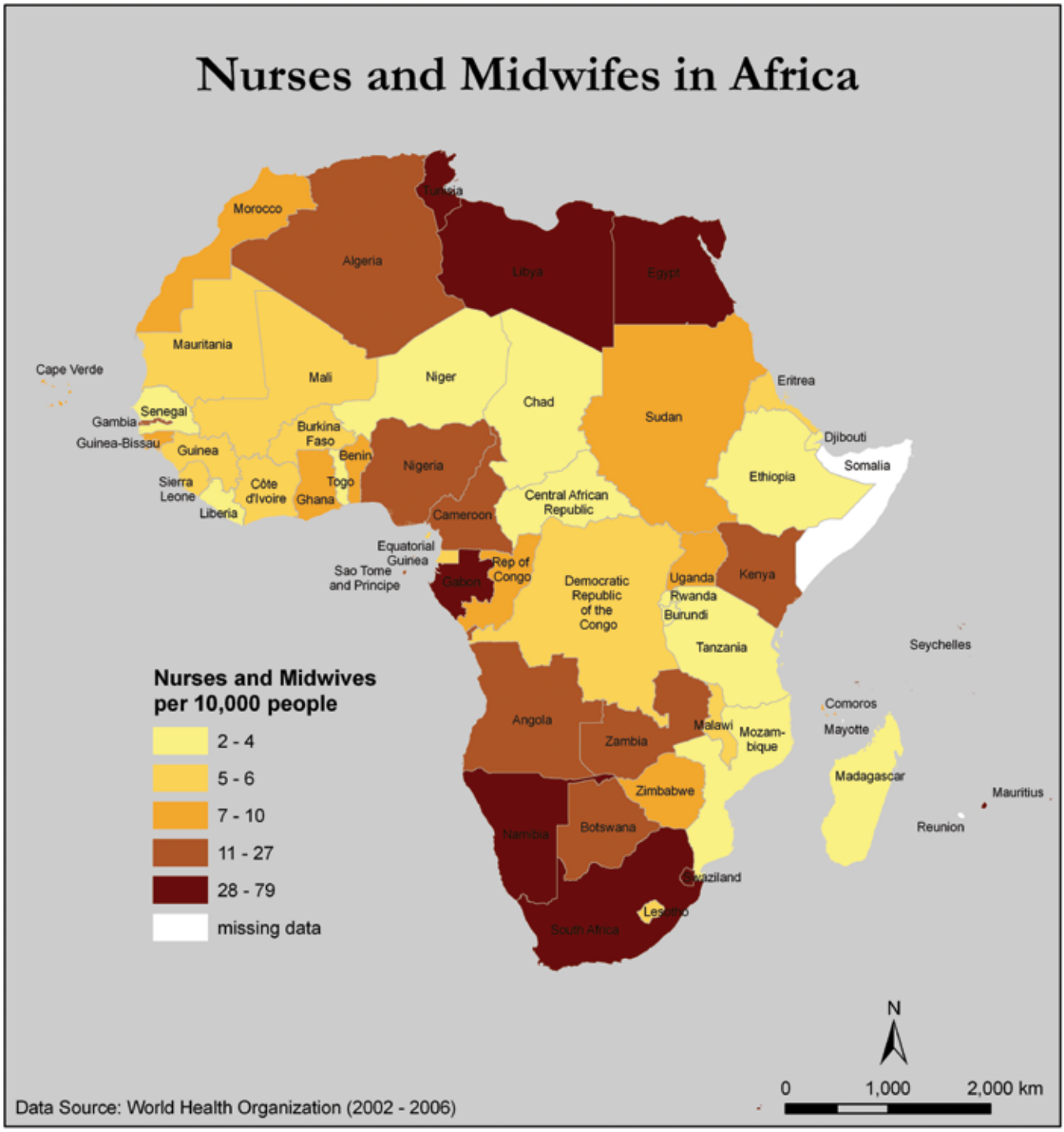

Infant Mortality Rates in Africa
Tunisia
Morocco
Algeria
Libya
Egypt
Cape Verde
Eritrea
Chad
Sudan
Gambia
Senegal
Guinea-Bissau
Djibouti
Somalia
Benin
Nigeria
Côte d'Ivoire
Ghana
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Seychelles
Comoros
Mayotte
Madagascar
Mauritius
Reunion
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
Infant Mortality Rate
(per 1,000 live births)*
4 - 50
51 - 72
73 - 99
100 - 119
120 - 203
missing data
N
0
1,000
2,000 km
Data Source: Center for International Earth Science
Information Network (CIESIN) (1991-2003)
*adjusted to national 2000 UNICEF rate


Life Expectancy at Birth in Africa (2006)
Tunisia
Morocco
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Eritrea
Sudan
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Togo
Ghana
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozam-bique
Madagascar
Zimbabwe
Mauritius
Reunion
Namibia
Botswana
Swaziland
Lesotho
South Africa
Life Expectancy at Birth (years)
62 - 73
57 - 61
52 - 56
47 - 51
40 - 46
N
0
1,000
2,000 km
Data Source: World Health Organization

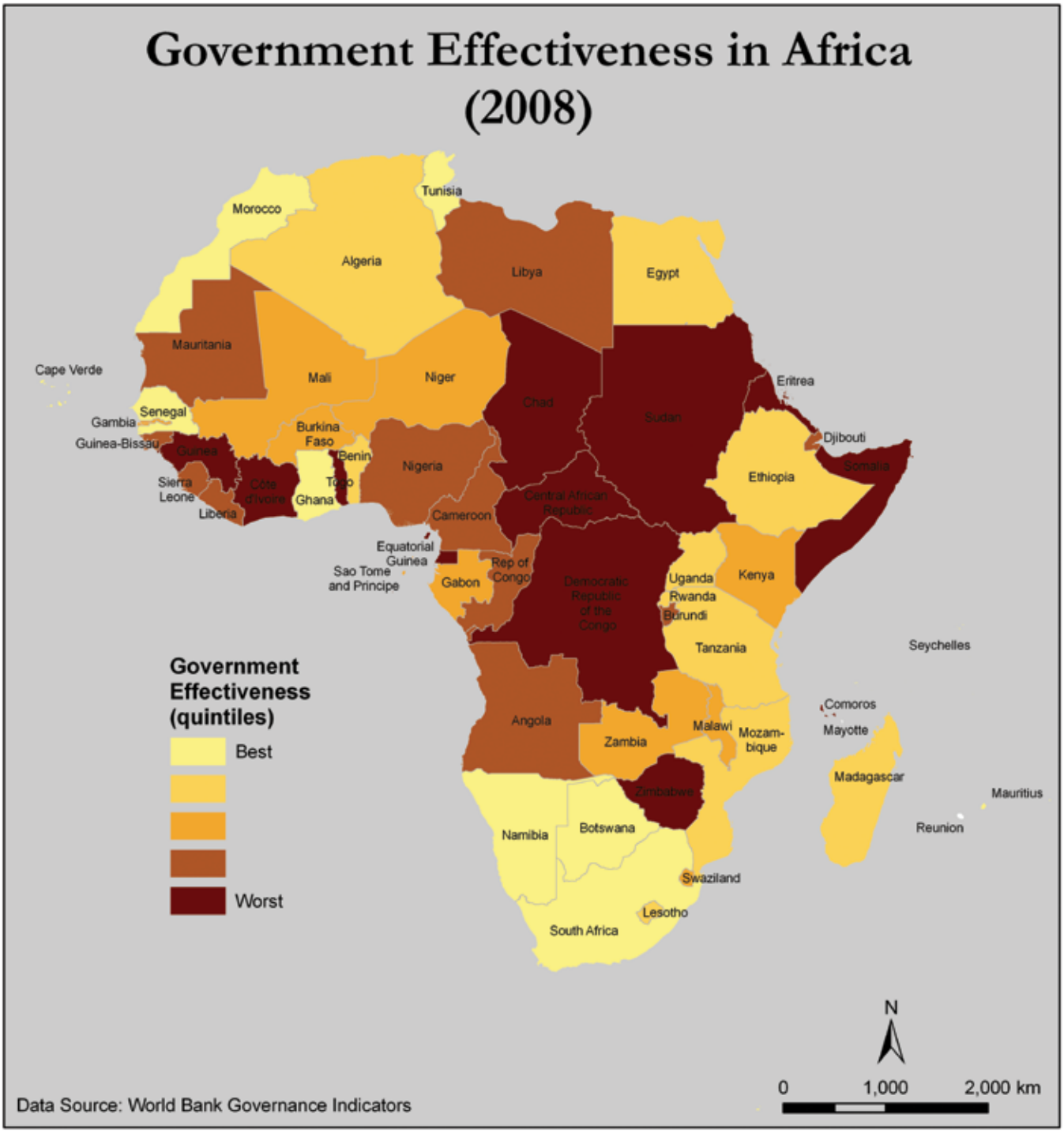

Childhood Malnutrition Rates in Africa
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Somalia
Ethiopia
Gambia
Senegal
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Sierra Leone
Liberia
Cote d'Ivoire
Togo
Ghana
Cameroon
Central African Republic
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozambique
Madagascar
Zimbabwe
Mauritius
Reunion
Namibia
Botswana
Swaziland
Lesotho
South Africa
% of Children
0 - 5-years-old
Underweight
1.1 - 11.6
11.7 - 21.0
21.1 - 27.1
27.2 - 34.9
35.0 - 54.7
missing data
N
0
1,000
2,000 km
Data Source: Center for International Earth Science
Information Network (CIESIN) (1990-2002)

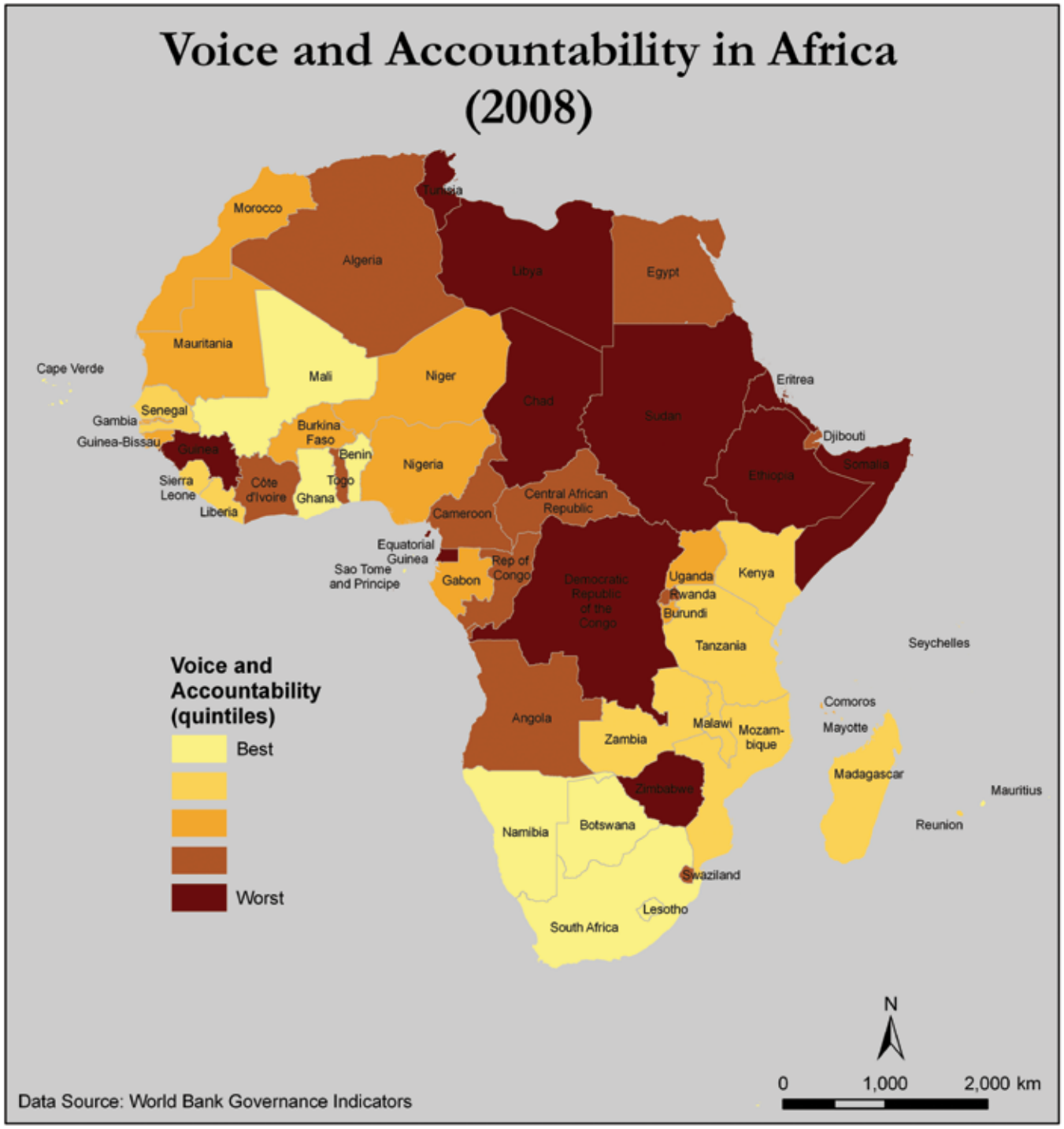

Drinking Water Accessibility in Africa
Tunisia
Morocco
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Somalia
Ethiopia
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Cameroon
Central African Republic
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Madagascar
Mauritius
Reunion
Angola
Zambia
Malawi
Mozam-bique
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
% of Population with Access to Improved Drinking Water Sources
87 - 100
77 - 86
65 - 76
54 - 64
29 - 53
N
0
1,000
2,000 km
Data Source: World Health Organization
(2006; 2000 for Cape Verde and Seychelles)

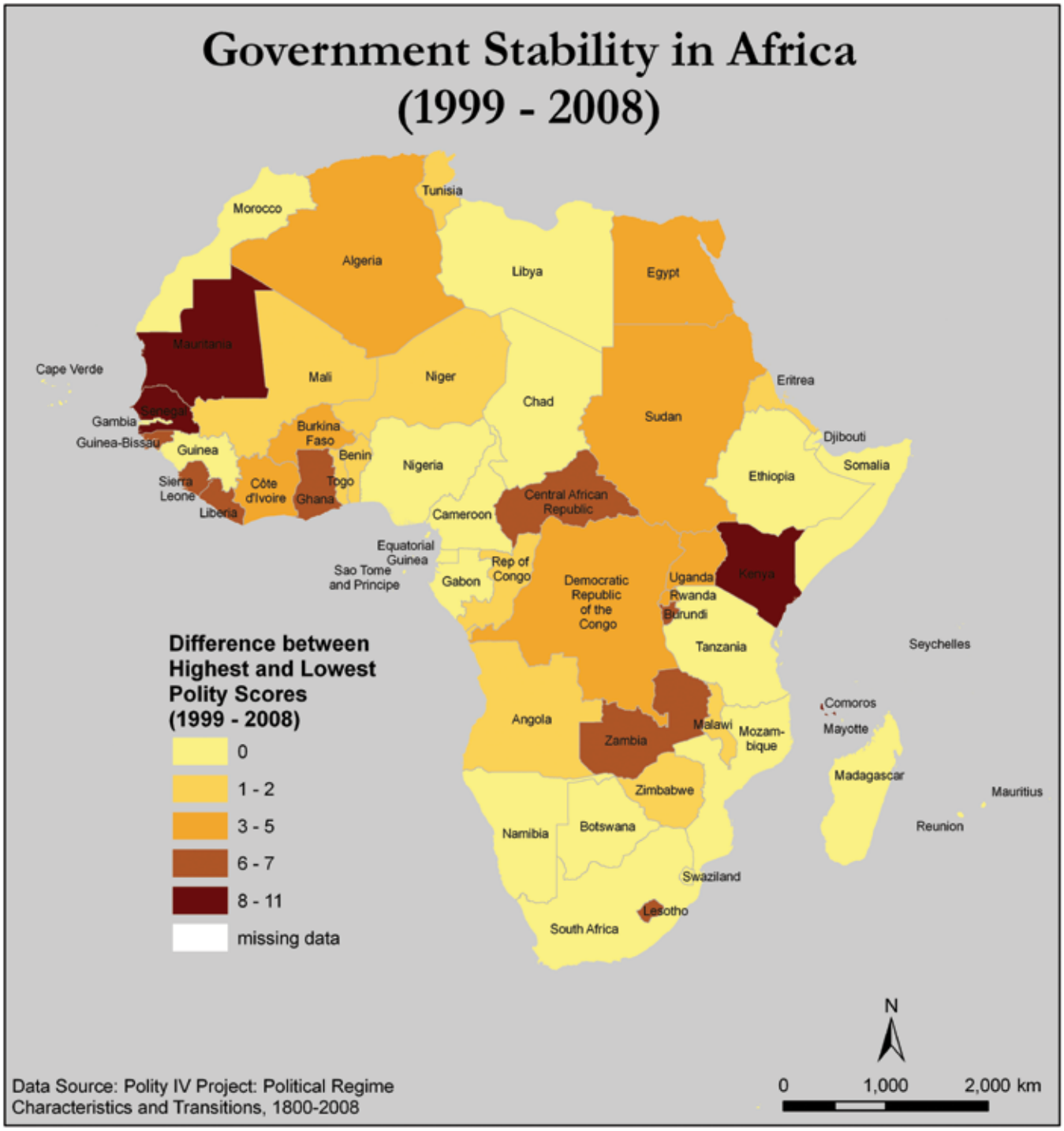

Healthcare Expenditures in Africa
Tunisia
Morocco
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Somalia
Ethiopia
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Sierra Leone
Liberia
Côte d'Ivoire
Togo
Ghana
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Madagascar
Mauritius
Reunion
Angola
Zambia
Malawi
Mozam-bique
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
Total Healthcare Expenditures (PPP int. $ per capita)
274 - 869
106 - 273
66 - 105
41 - 65
15 - 40
N
0
1,000
2,000 km
Data Source: World Health Organization (2006, 2001 for Somalia)

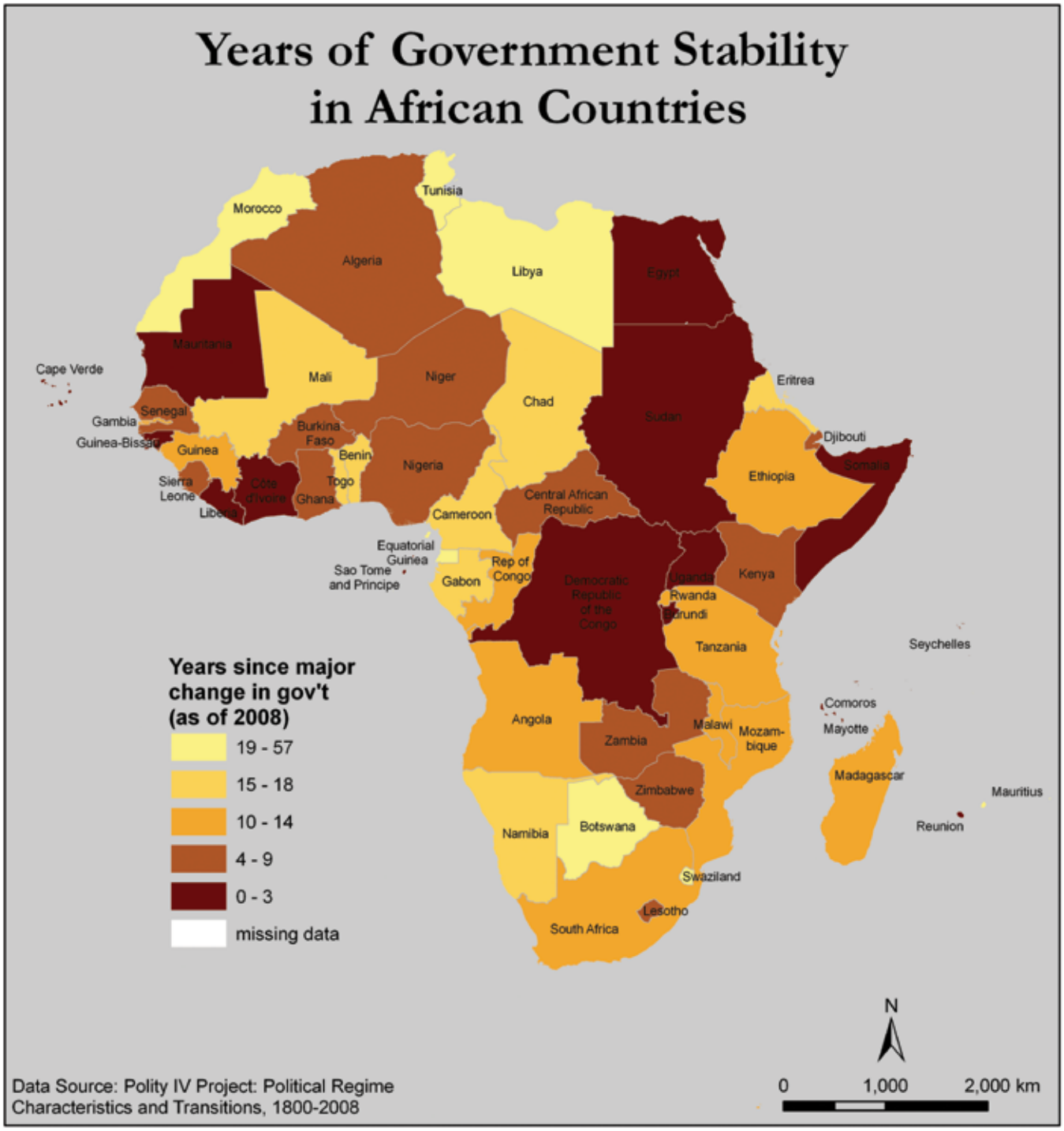

Nurses and Midwifes in Africa
Morocco
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Somalia
Ethiopia
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Cameroon
Central African Republic
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Madagascar
Mauritius
Reunion
Angola
Zambia
Malawi
Mozam-bique
Zimbabwe
Botswana
Namibia
Swaziland
Lesotho
South Africa
Nurses and Midwives per 10,000 people
2 - 4
5 - 6
7 - 10
11 - 27
28 - 79
missing data
N
0
1,000
2,000 km
Data Source: World Health Organization (2002 - 2006)

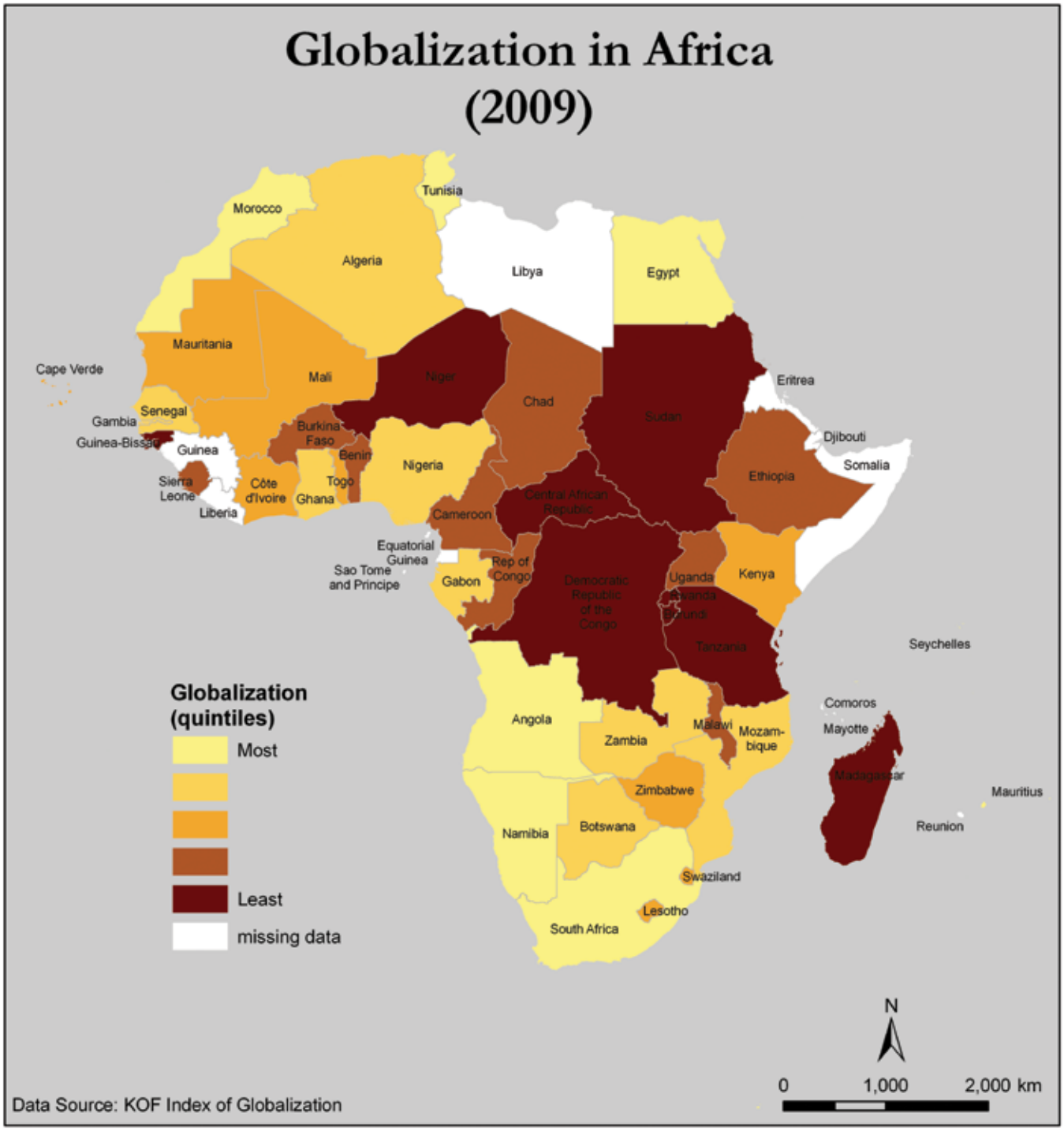
Appendix G: Indicators of Governance Level and Political Violence Vulnerability

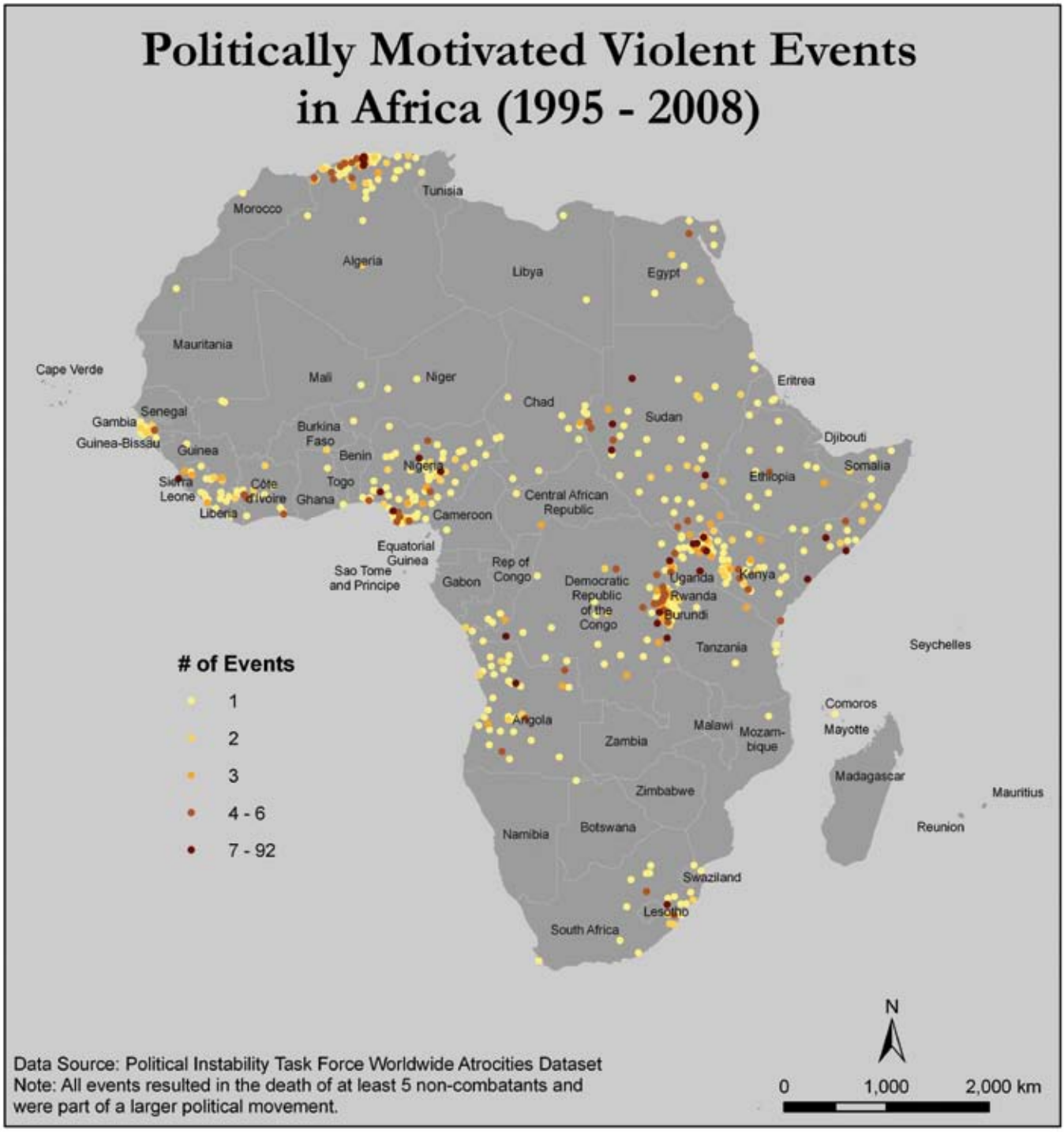



Voice and Accountability in Africa
(2008)
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozam-bique
Madagascar
Mauritius
Reunion
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
Voice and Accountability (quintiles)
Best
Worst
N
0
1,000
2,000 km
Data Source: World Bank Governance Indicators


Government Stability in Africa
(1999 - 2008)
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Gambia
Senegal
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Côte d'Ivoire
Togo
Ghana
Liberia
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozam-bique
Madagascar
Mauritius
Reunion
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
Difference between Highest and Lowest Polity Scores (1999 - 2008)
0
1 - 2
3 - 5
6 - 7
8 - 11
missing data
N
0
1,000
2,000 km
Data Source: Polity IV Project: Political Regime Characteristics and Transitions, 1800-2008


Years of Government Stability in African Countries
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Gambia
Senegal
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozam-bique
Madagascar
Zimbabwe
Mauritius
Reunion
Namibia
Botswana
Swaziland
Lesotho
South Africa
Years since major change in gov't (as of 2008)
19 - 57
15 - 18
10 - 14
4 - 9
0 - 3
missing data
N
0
1,000
2,000 km
Data Source: Polity IV Project: Political Regime Characteristics and Transitions, 1800-2008


Globalization in Africa
(2009)
Morocco
Tunisia
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Rwanda
Burundi
Kenya
Tanzania
Seychelles
Comoros
Mayotte
Madagascar
Mauritius
Reunion
Angola
Zambia
Malawi
Mozam-bique
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
Globalization (quintiles)
Most
Least
missing data
N
0
1,000
2,000 km
Data Source: KOF Index of Globalization


Politically Motivated Violent Events in Africa (1995 - 2008)
Tunisia
Morocco
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Eritrea
Chad
Sudan
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Central African Republic
Cameroon
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozam-bique
Madagascar
Zimbabwe
Mauritius
Reunion
Namibia
Botswana
Swaziland
Lesotho
South Africa
# of Events
1
2
3
4 - 6
7 - 92
N
0
1,000
2,000 km
Data Source: Political Instability Task Force Worldwide Atrocities Dataset
Note: All events resulted in the death of at least 5 non-combatants and were part of a larger political movement.

ENDNOTES

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[3] This project was initiated in June 2009, and this paper represents the first effort at combined GIS-based sub-national climate security maps, using existing data sources. Other members of the team are coding new data: team member Clionadh Raleigh has developed the Armed Conflict and Location Event Data (ACLED); team members Idean Salehyan and Cullen Hendrix are coding data on strikes and riots in their new Social Conflict in Africa Database (SCAD); and team members Kate Weaver, Timmons Roberts, and Michael Tierney are geo-coding climate adaptation projects under the Project-Level Aid Database. This paper makes use of existing geo-coded data sources to provide a preliminary proof of concept. An earlier version of this paper was presented at the conference on "Climate Change, Social Stress, and Violent Conflict" in Hamburg, Germany in November 2009.

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[25] Raleigh and Jordan 2008.

[26] Appendix A includes Raleigh and Jordan's list of most vulnerable countries.

[27] Basher and Briceño 2005, p. 276.

[28] Levy et al. 2008.

[29] The measures of instability and dangerous neighborhood are derived from the Political Instability Task Force. Levy et al. calculated the number of major instability events between 1992 and 2005. Countries with 30 or more events were considered "extremely high" in terms of instability. Countries whose neighbors had 30 or more events were considered "very dangerous."

[30] Appendix B summarizes several of the Levy et al. model permutations in a single chart.

[31] Brooks, Adger, and Kelly 2005.; For a more extended discussion of their methodology, see Adger, W. Neil, Nick Brooks, Graham Bentham, Maureen Agnew, and Siri Eriksen. 2004. *New indicators of vulnerability and adaptive capacity*. Tyndall Center for Climate Change Research, January 2004. Available from www.tyndall.ac.uk/sites/default/files/it1_11.pdf.

[32] In this regard, the research by Brooks, Adger, and Kelly is similar to CCAPS' research partners Timmons Roberts and Bradley Parks. Whereas Brooks and his colleagues appear to serially test the significance of individual variables, Roberts and Parks seek to explain disaster mortality through multivariate regression. The variables Roberts and Parks tested included GDP per capita, the Gini coefficient, two attributes of geographical vulnerability (population near coasts and population near cities), environmental vulnerability, civil society pressure, and two measures of institutional quality (press freedom and property rights). In finding higher disaster mortality vulnerability among countries in the developing world, they ultimately attribute many of the problems to their colonial heritage and the ways in which developing countries have become inserted in the global economy as exporters of primary commodities. See Roberts, J. Timmons, and Bradley C. Parks. 2007. *A climate of injustice: global inequality, North-South politics, and climate policy, Global environmental accord*. Cambridge, UK: MIT Press.

[33] Appendix C includes the list of top countries vulnerable to climate disasters, as determined by Brooks et al.

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[35] Exposure reflects the nature and extent of climate change likely to affect a place. Sensitivity reflects how systems could be negatively affected by climate change, how much land could be inundated by sea level rise, how crop yields might change, and how human health might be affected. Adaptive capacity reflects how much capability the society has to adapt to changes to minimize losses. Brenkert and Malone 2005, p. 63-64.

[36] Sensitivity indicators include: *food security* represented by (1) cereals production/crop land area and (2) protein consumption/area; *water resources* represented by (3) renewable supply and inflow and (4) water use; *settlement/infrastructure* represented by (5) population at flood risk and (6) population with no access to clean water/sanitation; *human health* represented by (7) completed fertility and (8) life expectancy; and *ecosystem* represented by (9) % of land managed and (10) fertilizer/cropland area.

[37] Adaptive capacity indicators include: *environmental capacity* represented by (11) population density, (12) sulfur dioxide/state area, and (13) % of land unmanaged; *economic capacity* represented by (14) GDP per capita and (15) income equity; and *human and civic resources* represented by (16) dependency ratio and (17) literacy.

[38] Sen, Amartya. 1981. *Poverty and famines: An essay on entitlement and deprivation*. Oxford, UK: Oxford University Press.

[39] King, Marcus D., and Ralph H. Espach. 2009. *Global Climate Change and State Stability*. Washington, DC: CNA Corporation.

[40] Yohe et al. 2006, p. 3.

[41] Moreover, some of the variables they include, such as sulfur dioxide emissions, appear either irrelevant to climate change or are poor proxies for the underlying processes that they are meant to reflect.

[42] Yohe et al. 2006. The authors use the Environmental Sustainability Index, which is highly correlated with the VRIM to impute values for six African countries: Chad, Mauritania, Mali, Namibia, Niger, and Zambia.

[43] Appendix D includes the top tertile of the 102 most vulnerable countries, as defined by Brenkert and Malone.

[44] Cardona expresses a similar framework identifying the origins of vulnerability in physical fragility or exposure, socio-economic fragility, and lack of resilience. See Cardona 2004, p. 49.

[45] UNEP/GRID-Europe. 2009. *Global Risk Data Platform*, May 15, 2009. Available from www.preventionweb.net/english/maps/index.php.

[46] The Environmental Systems Research Institute (ESRI) describes a raster file as follows: "In its simplest form, a raster consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information." ESRI. *ArcGIS 9.2 Desktop Help*. September 22, 2008. Available fromhttp://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=What_is_raster_data?; ESRI describes that: "A shapefile stores geometry and attribute information for the spatial features in a data set. The geometry for a feature is stored as a shape comprising a set of vector coordinates. Shapefiles can support point, line, and area features." Environmental Systems Research Institute. *ESRI Shapefile Technical Description, An ESRI White Paper*. July 1998. Available from www.esri.com/library/whitepapers/pdfs/shapefile.pdf.

[47] USGS. 2009. *GTOPO30*. United States Geological Service, October 20, 2009. Available from http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info.

[48] Appendix E has detailed maps of each indicator included in this study.

[49] Brooks et al. ultimately made a similar choice.

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[51] WHO. 2009. *WHO Statistical Information System*. World Health Organization. Available from http://apps.who.int/whosis/data/Search.jsp.

[52] FAO. 2009. *Food Security Statistics*. Food and Agriculture Organization. Available from www.fao.org/economic/ess/food-security-statistics/en.

[53] CIESIN 2005.

[54] Appendix G provides detailed maps of each component of the governance and political violence basket.

[55] Brooks et al. 2005.

[56] World Bank. 2009a. *Governance Matters 2009*. Available from http://info.worldbank.org/governance/wgi/index.asp.

[57] Freedom House. 2008. *Methodology*. Available from www.freedomhouse.org/template.cfm?page=351&ana_page=341&year=2008.

[58] KOF. 2009. *KOF Index of Globalization*. Available from http://globalization.kof.ethz.ch.

[59] Polity IV Project. 2009. *Polity IV Project: Political Regime Characteristics and Transitions, 1800-2008*. Available from www.systemicpeace.org/polity/polity4.htm.

[60] KEDS. 2009. *Political Instability Task Force Worldwide Atrocities Dataset*, January 8. Available from http://web.ku.edu/~keds/data.dir/atrocities.html.

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[66] Cederman, Lars-Erik, Brian Min, and Andreas Wimmer. 2009. *Ethnic Power Relations dataset*. ETH-Zurich and UCLA. Available from www.epr.ucla.edu.

[67] UNISDR 2009, p. 57.

[68] The data for climate risk is based on 2030 projections. The data for political risk is based on historical data of three indicators of instability (dangerous neighborhood 1992-2005, crisis history 1990-2005, and low capacity from the World Bank Government Effectiveness indicators [dates not specified]). The first column on coastal population exposure and population exposed is based on countries with two or more instability risk factors (dangerous neighborhood, crisis history, low capacity), sorted by population based on the number of people projected to be living within 1 meter of the low elevation coastal zone (LECZ), 2030. The second column on coastal population % of population is based on the same as above two or more instability factors but the highest % of projected population in 2030 within 1 meter of the low elevation coastal zone (LECZ). The middle column on aggregate temperature change is based on countries with two or more risk factors (low capacity, high crisis history, dangerous neighborhood), climate vulnerability 2030, A1 Scenario. The final column on water scarcity is based on countries with two or more instability factors, sorted by change in percentage of population in water scarcity (2000-2030).

[69] On the basis of thirteen weighting schemes, these are the countries Brenkert and Malone identified as most vulnerable to climate disaster mortality; they appeared in the upper quintile of all thirteen weighting schemes.

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