

CCAPS  CLIMATE CHANGE
AND AFRICAN
POLITICAL STABILITY



VULNERABILITY TO CLIMATE CHANGE:

Water Resource Stress and Food Insecurity in Southern Africa

STUDENT WORKING PAPER NO. 1

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Edited by Dr. Joshua Busby, Kaiba White, and Todd Smith



Photo credit: Todd Smith

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 the University of Texas at Austin, the College of William and Mary, Trinity College Dublin, and the University of North Texas.

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.

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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

According to the Intergovernmental Panel on Climate Change, climate change will disproportionately affect the most vulnerable populations in the developing world. Rising temperatures, increasingly severe floods and droughts, and sea-level rise threaten economies that are reliant on agriculture, in countries whose governments lack adaptive capacity, and in areas where populations have little access to healthcare and education.

A graduate student research team working with the Climate Change and African Political Stability (CCAPS) program used Geographic Information Systems (GIS) to identify the regions at greatest risk across Africa.¹ This regional study on southern Africa includes Angola, Botswana, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe. This study examines the potential impact of a confluence of factors on countries' overall vulnerability and their ability to minimize the effects of climate change.

This study focuses in particular on resilience to stress on water resources, considering southern Africa's dry climate and reliance on transboundary river basins and groundwater for agriculture, industry, and consumptive use. The study also focuses on water resource management institutions and governments' capacity to respond to changes in rainfall patterns. Droughts in the region are becoming longer and more severe, while rainfall patterns vary greatly, leaving farmers less able to predict harvests. Floods are made worse by drought-stricken land's inability to absorb heavy rains, which causes runoff and flash floods. Combined, the severe drought-flood cycle can destroy crops quickly and cause permanent soil degradation that results in long-term declines in agricultural output.

The areas in southern Africa that will be most affected by climate change are identified using a variation of the CCAPS vulnerability assessment model.² The model for southern Africa measures climate change vulnerability by examining five main sources or "baskets" of vulnerability: population density, historical exposure to climate-related hazards, household and community vulnerability, governance, and resilience to stress on water resources. These sources of vulnerability are described as "baskets" since they typically each contain multiple indicators.

Climate change will have the largest impact on areas that have high population density, significant historical exposure to climate-related hazards, high household vulnerability, poor governance, and low resilience to stress on water resources. Population density is included because of the study's concern with where and how climate change will affect people. Historical exposure to climate-related hazards—including floods, droughts, cyclones, and fires—is used as an indicator of possible future exposure to climate change. The household and community vulnerability basket is made up of health and education indicators, and is included to measure a population's ability to respond to climate crises. Where governance is poor, it is expected that the government's inability or unwillingness to minimize risk to the population will exacerbate the effects of climate change. Finally, the resilience to stress on water resources basket measures a country's ability to manage changes in rainfall patterns based on current levels of water availability and use, the population's access to improved drinking water, and dependency on water from other countries. These five baskets together constitute the composite vulnerability model used in this study on southern Africa. This is used to identify the areas of southern Africa that are most vulnerable to the impacts of climate change.

According to this model, the most vulnerable parts of the region are Zimbabwe, Madagascar, and the southeastern coast of Africa. Zimbabwe is extremely vulnerable, largely due to its poor governance and extreme flood and drought cycles. Madagascar's vulnerability can be attributed to its poor scores on household and community indicators and its susceptibility to cyclones from the Indian Ocean. Much of the region's most vulnerable areas lie within the Zambezi River basin; this

highlights the importance of examining water resource management and shared water supplies for evaluating climate change impacts. Countries will have to assess their own institutional weaknesses, work with neighboring governments to design effective water management agreements, and coordinate responses to climate-related disasters.

Climate change is expected to cause increasingly severe floods and droughts in the southern Africa region, threatening the reliability of agricultural output and increasing the risk of food insecurity. This is both an immediate and a long-term concern, and future research should focus on connections between protracted food insecurity and varying degrees of conflict. While the findings of this paper show that large areas in southern Africa are extremely vulnerable to climate change and could face serious food insecurity in the near future, responsible water management in the region could lessen the risk of severe shortages. The southern Africa region is home to 11 transboundary river basins, making international cooperation over the equitable allocation, sustainable use, and efficient distribution of water resources key to the region's ability to manage the impacts of climate change on populations and economies.

INTRODUCTION

Prologue: Flood and Drought

In March 2009, several days of flood rains claimed more than 100 lives and threatened the food security of 500,000 people in Namibia. Those most affected were subsistence farmers in the north. Heavy seasonal rains in Zambia caused flooding that caused five million dollars in damages, cut off access to roads, destroyed schools, and displaced hundreds of thousands of people. Across the region, flooding increased the threat of outbreaks of diseases like malaria and cholera.³

In February 2010, Mozambique's Ministry of Agriculture estimated that persistent drought caused the loss of 605,000 hectares of planted land, devastating 13 percent of maize production and 11 percent of cereals. The World Food Programme estimated that 465,000 Mozambicans would need food aid as a result, as extreme drought and subsequent flooding exacerbated already precarious food security conditions. Some 100,000 people who moved from Mozambique's drought-affected areas suffered flooding after their arrival in low-lying river basins.⁴

Climate change is expected to bring both more extreme drought and violent rainy seasons to southern Africa. As rainy seasons become shorter and floods more extreme, soil degradation could threaten the livelihoods of farmers in the region. Droughts could become longer and more intense as the region's deserts expand, exposing a growing population to increasing food security challenges. The impacts of climate change are not limited to the damaging effects caused by increased drought and flood. Conflict, increased groundwater mining, and the depletion of trans-boundary river basins test fragile international agreements governing cooperative water management as countries become more concerned with their national interest than collective water security. While cooperation over shared resources has proved successful in the past, barriers to collective action could become greater in the future as resources decline.

Climate variability will exacerbate the already increasing demand on water resources for consumption, power generation, and agriculture—the largest user of water in southern Africa. Water availability in southern Africa is a pressing concern for those whose next meal depends on rain-fed agriculture and for those who want to ensure continued access to water long into the future. Identifying which countries in the region are least prepared to respond to changing rainfall patterns can support policymakers and stakeholders in addressing both the short- and long-term concerns involving water availability and help minimize the impacts of climate change.

Purpose and Scope

This paper seeks to provide a region-specific framework in which to study climate change vulnerability in southern Africa, shown in Figure 1. There are 11 countries included in this study: Angola, Botswana, Lesotho, Madagascar, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe. This study is conducted in five parts. Part 1 provides geographical, political, and economic background on southern Africa and explores which parts of the region are particularly vulnerable to climate change. To do so, it assesses current events and relevant academic literature in political science, resource management policy, and climatology. It also addresses the political context—how the region manages resources and addresses climate-related concerns, either at the state level or through international treaties.

Part 2 explains the methodology used to assess vulnerability to climate change in southern Africa on the basis of five main sources, or “baskets,” of vulnerability. This section begins with a brief overview of previous studies on climate change vulnerability and continues with the rationale for including a basket that highlights pressure on water resources in the region. Part 3 analyzes three composite maps showing various dimensions of vulnerability and outlines the choices for case study subjects in Part 4. Part 4 consists of case studies on the Limpopo River Basin, Zambezi River Basin, and government response to water-related concerns in Zimbabwe. Part 5 reviews the implications for water management and food security. The conclusion summarizes the findings and makes recommendations for future work.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

POLITICAL BOUNDARIES AND GEOGRAPHY

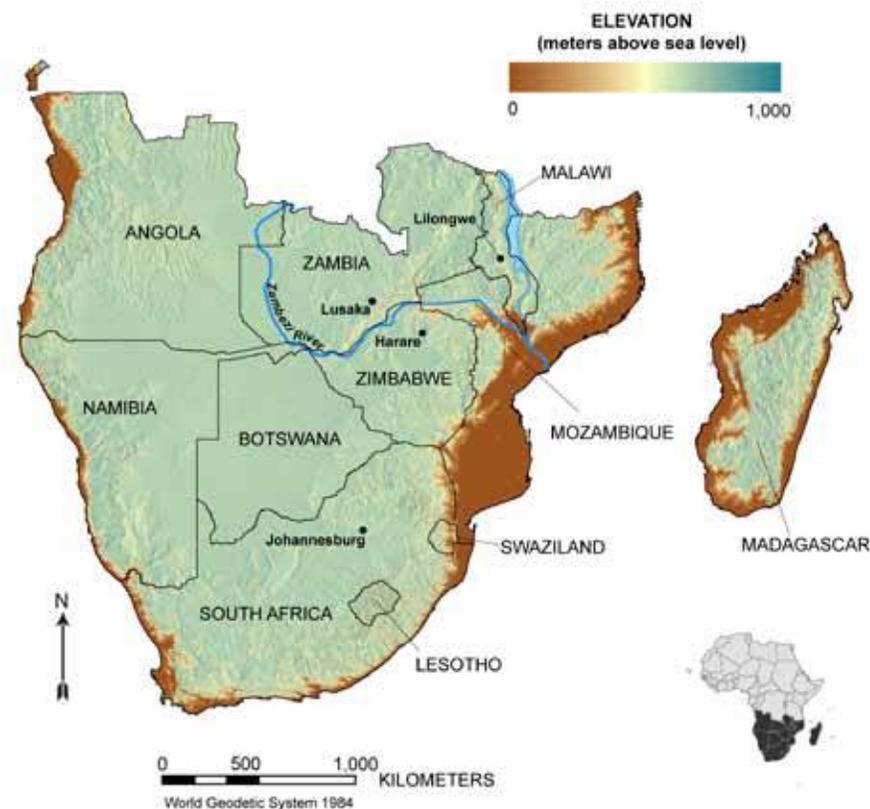


FIGURE 1.
For data sources please see Appendix 4.

PART 1: SOUTHERN AFRICA IN PERSPECTIVE

Climate Change in Southern Africa

In 2007, the Intergovernmental Panel on Climate Change (IPCC) reported that those living in the world's poorest countries would be most affected by climate change. Compiled with regional data not available in previous IPCC assessments, the report suggests that yields from rain-fed agriculture could fall by half in some African countries, and between 75 and 250 million people in Africa could face water shortages by 2020. It warns that coastal regions are susceptible to rising sea levels by the end of the 21st century and that Africa's multiple stresses and limited adaptive capacity to climate variability make the continent particularly vulnerable to climate change.⁵ The report includes model simulations of changes in precipitation, evaporation, and runoff over the next century, due to climate change. Two southern Africa basins—the Zambezi and Limpopo—are projected to have some of the largest changes on the continent and will be the subject of case studies in Part 4. While the IPCC reports estimates of climate change impacts beginning in 2017, recent events in southern Africa indicate what can be expected as climate variability becomes increasingly severe. Southern Africa is already experiencing intense droughts and floods; these events will only become more numerous and severe as the impacts of climate change continue.

Floods destroy crops and level homes instantly, but they also cause long-term public health concerns that governments can find difficult to handle. To prevent swelling rivers from damaging reservoir infrastructure, governments often have to open dams despite the risk of drinking water contamination that follows heavy flooding. In 2003, the Namibian Red Cross reported that flood victims in the Caprivi region of Namibia between South Africa and Botswana faced infectious flies, deadly mosquitoes, and contaminated drinking water as flood waters subsided.⁶ Namibia's 2009 flood, the country's worst in 34 years, submerged towns when the Hardap dam was opened to discharge more than 500 meters of water per second—a level that exceeded the dam's capacity.⁷

While severe flooding tests the ability of existing infrastructure to minimize flood damage, devastating seasonal droughts threaten food security and force governments to contend with competing demands for scarce water resources. For many years, southern Africa investigated hydropower as a solution to its energy deficit, but a 2009 University of Cape Town study warned that the region might soon have to choose between lights and drinking water.⁸ If scarce resources are used to expand access to electricity in the region, people could be left without water. The management of water resources involves considerations for industry, public health, security, and sustainable development. Several international agreements recognize the difficulty posed by water resource management and development, and attempt to operationalize a comprehensive and responsible framework for water use in southern Africa. Despite governments' recognition of the importance of transboundary water resource management, institutions are notoriously weak and fail to enforce the agreements.

In 1992, 15 founding states signed the Southern African Development Community (SADC) Agreement. Intended to facilitate economic integration and development in the region, SADC also serves to help member states regulate use of shared water resources. In 2001, member states signed the SADC Revised Protocol on Shared Watercourse Systems, an agreement that established guidelines for responsible use of the 11 international river basins in the region. While the agreement outlined how countries should manage shared water resources, it did not establish a regulatory institution to ensure compliance. Each country in the region approaches water management differently, making coordination difficult and causing disputes across borders. The impact of climate change is greatest where people rely on shared water resources and in areas already vulnerable to severe droughts and floods. The lack of effective water management institutions could exacerbate the existing risks that climate change poses to the region. Despite

its ineffectiveness to date, the SADC Water Protocol is evidence that governments in southern Africa are working to address water management and its potential as a source of tension in the region. Such efforts could be the basis for future institutional development in water resource management.

PART 2: METHODOLOGY

Background on Vulnerability

The IPCC's Fourth Assessment Report 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."⁹ Vulnerability is not a purely physical measurement—it is a confluence of geography, socio-economic factors, and governance. It is bad luck in geography, poor health and economic outcomes, and poor governance that make a place most vulnerable to negative outcomes from climate change.

Much of the literature on using vulnerability indices to measure potential effects of climate change stresses that indices allow for multi-dimensional analysis of a complex problem. The impacts of climate change in southern Africa will be variable and various factors will affect governments' relative ability to respond to these effects.

Geographic Information Systems (GIS) allows researchers to display a large amount of data at once. The GIS-based vulnerability index for southern Africa employed here differs only slightly from earlier continent-wide work by Busby et al., which used four baskets: historical exposure to climate-related hazards; population density; household and community vulnerability; and governance. This study includes one additional basket that resembles portions of the Vulnerability-Resilience Indicators Model (VRIM) and measures the resilience to stress on water resources (hereafter referred to as "water" or "water resilience").¹⁰ This basket is in part a measure of human access to water and in part a measure of environmental and infrastructural capacity to manage disasters related to floods and droughts. It does not include data on flood or drought frequency, because this is encompassed in the historical exposure to climate-related hazards. The basket attempts to assess how well a government can react to environmental shocks and stresses on water resources. While this model was designed specifically to study southern Africa, the fifth basket might be modified in other studies to include data relevant to other regions.

Figures 2 through 6 show each individual basket in the vulnerability index for southern Africa: historical exposure to climate-related hazards, population density, household and community vulnerability, governance, and resilience to stress on water resources, respectively. There is one minor change to the model used by Busby et al. In this southern Africa study, access to improved water resources was moved from the household basket to the water basket. The percentage of underweight children was given double its original weight in the household basket to compensate because each other sub-basket of indicators includes two data points. Table 1 shows each component of the total vulnerability index with its weight and a reference to where maps of the individual indicators can be found in the appendix. While the important impact that future climate models might have on these results is understood, they are not included in this study's map-based analysis.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

POPULATION DENSITY

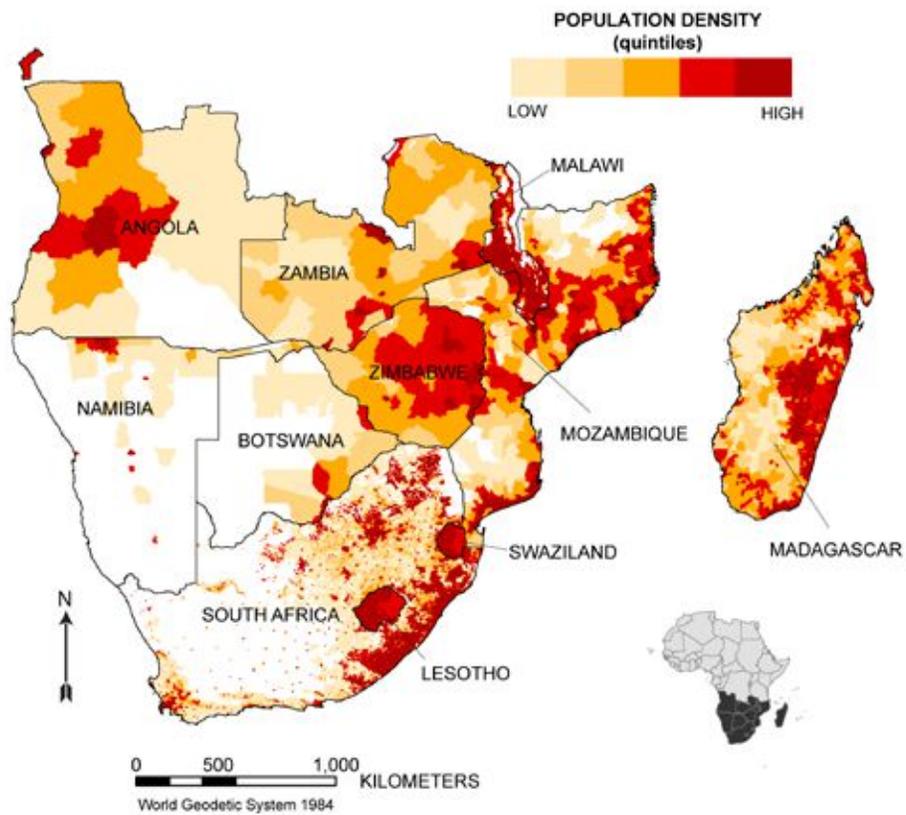


FIGURE 2.
HIGHER POPULATION DENSITY YIELDS GREATER VULNERABILITY TO CLIMATE CHANGE

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

HISTORICAL EXPOSURE TO CLIMATE RELATED HAZARDS

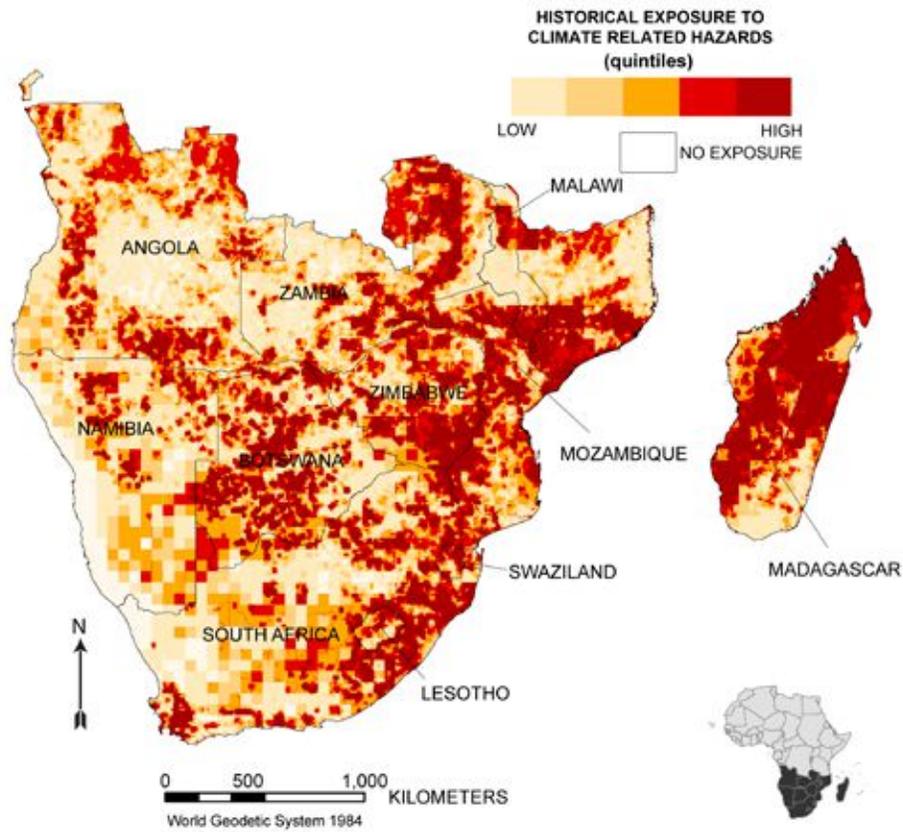


FIGURE 3.
HISTORICAL EXPOSURE TO CLIMATE RELATED HAZARDS IS MEASURED BY FOUR INDICATORS

- Drought events
- Flood frequency
- Cyclone surge frequency
- Fire density

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

HOUSEHOLD AND COMMUNITY VULNERABILITY

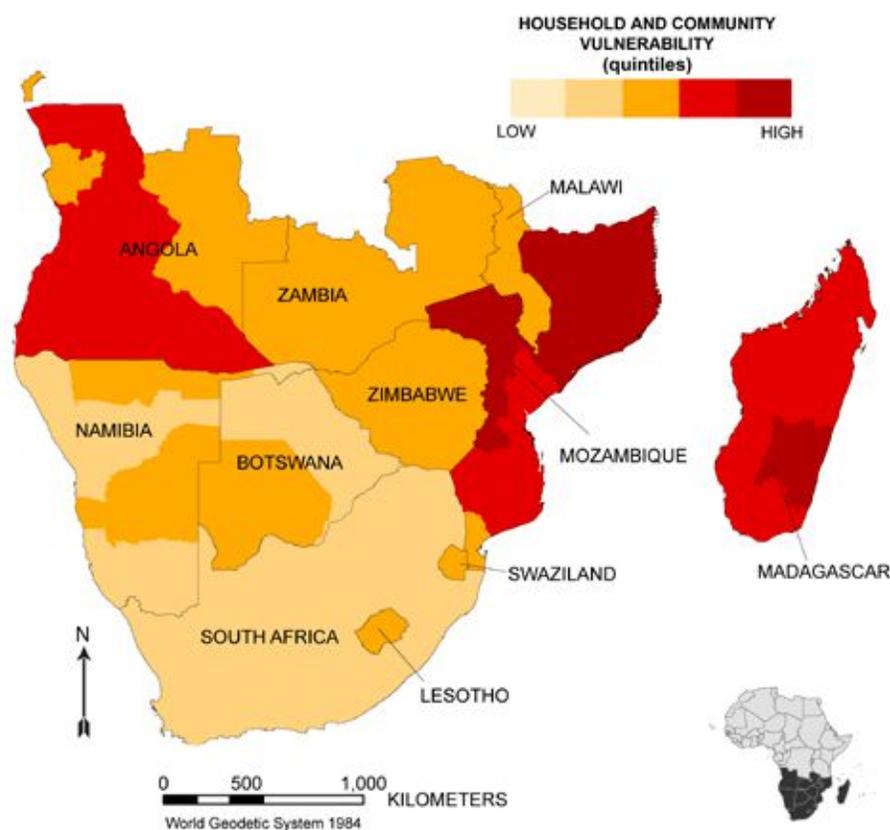


FIGURE 4.
HOUSEHOLD VULNERABILITY IS MEASURED BY SEVEN INDICATORS
ADULT LITERACY (higher level, lower vulnerability)
PRIMARY SCHOOL ENROLLMENT RATE (higher rate, lower vulnerability)
ADJUSTED INFANT MORTALITY RATE (higher rate, greater vulnerability)
LIFE EXPECTANCY AT BIRTH (higher number, lower vulnerability)
PERCENT OF CHILDREN UNDER FIVE WHO ARE UNDERWEIGHT (higher level, lower vulnerability)
TOTAL EXPENDITURE ON HEALTHCARE PER CAPITA (higher rate, higher vulnerability)
NURSING PERSONNEL DENSITY PER 10,000 POPULATION (higher density, lower vulnerability)
See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

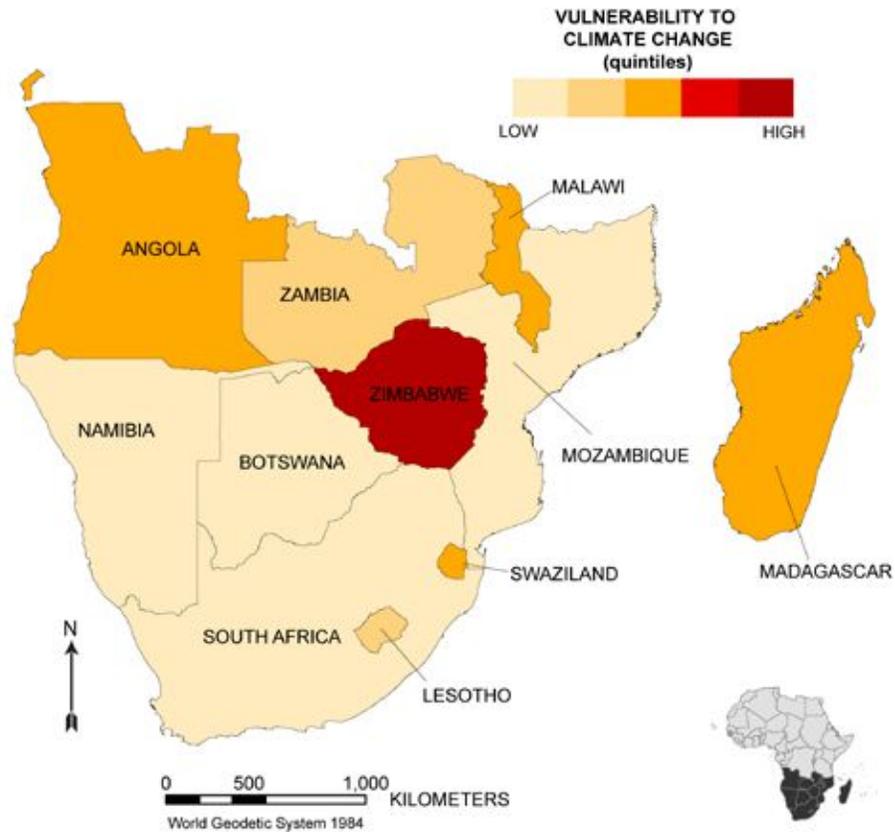
GOVERNANCE

FIGURE 5.
GOVERNANCE IS MEASURED BY SIX INDICATORS

VOICE AND ACCOUNTABILITY (higher level, better governance, lower vulnerability)
 POLITICAL STABILITY AND ABSENCE OF VIOLENCE (higher level, lower vulnerability)
 GOVERNMENT EFFECTIVENESS (higher level, lower vulnerability)
 REGULATORY QUALITY (higher level, lower vulnerability)
 RULE OF LAW (higher level, lower vulnerability)
 CONTROL OF CORRUPTION (higher level, lower vulnerability)

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

RESILIENCE TO STRESS ON WATER RESOURCES

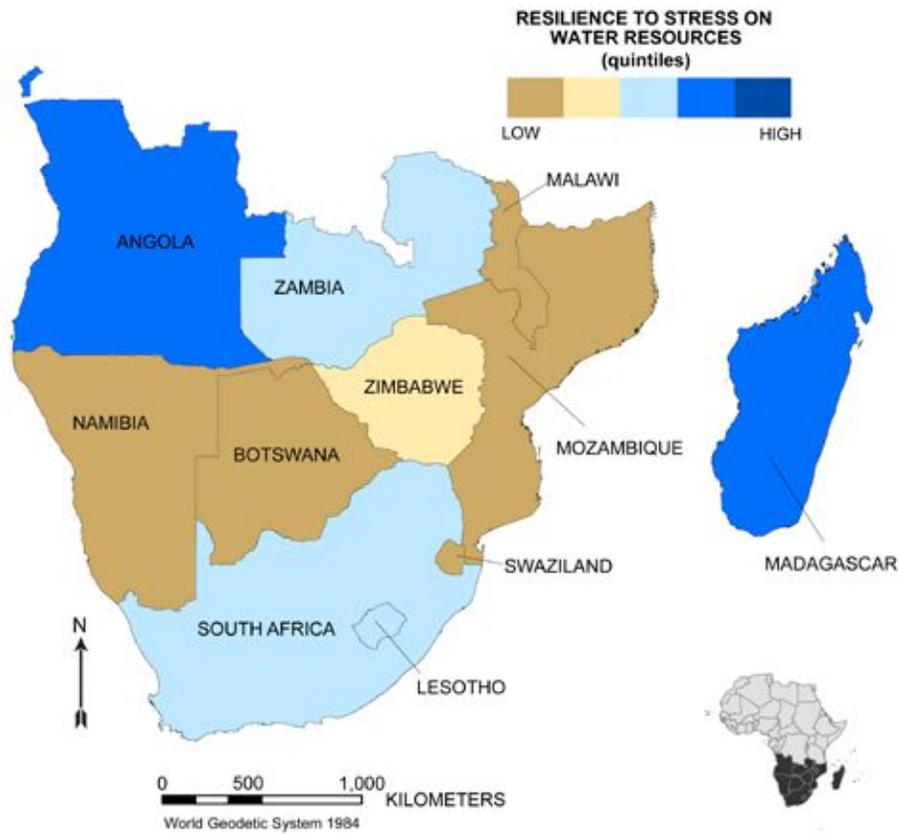


FIGURE 6.

RESILIENCE TO STRESS ON WATER RESOURCES MEASURED BY FIVE INDICATORS

- PERCENT OF POPULATION WITH ACCESS TO IMPROVED DRINKING WATER (higher percentage, higher resilience)
- DEPENDENCY RATIO (higher percentage, lower resilience)
- PERCENT OF TOTAL ACTUAL RENEWABLE FRESH WATER RESOURCES (higher percentage withdrawn, higher resilience)
- PERCENT OF TOTAL CROPLAND IRRIGATED (higher percentage, higher resilience)
- TOTAL ACTUAL RENEWABLE GROUNDWATER (higher percentage, higher resilience)

See Appendix 4 for data sources.

Consideration for climate change projections is limited to the rationale for the overall framework of the model. It will be important to include climate models of Africa and the southern Africa region in future iterations of this research, but unfortunately model projections of future climate change were not available in GIS-format at the time of writing of this report.

Table 1: Individual Indicator Weights in Total Composite Vulnerability Index

Index Component	Weight	Source
Resilience to Stress on Water Resources¹¹	.2	
<i>Access to improved drinking water</i>	.04	WDI, 2006
<i>Percentage of cropland irrigated</i>	.04	WDI, 2003
<i>Total actual renewable groundwater resources</i>	.04	AQUASTAT (1998-2002)
<i>Percentage of available freshwater withdrawn</i>	.04	AQUASTAT (2003-2007)
<i>Dependency ratio</i>	.04	AQUASTAT (2003-2007)
Climate-Related Hazards	.2	UNEP/GRID Europe (1980-2008)
<i>Cyclones wind intensity</i>	.04	
<i>Cyclones surges frequency</i>	.04	
<i>Floods frequency</i>	.04	
<i>Fire density</i>	.04	
<i>Droughts events</i>	.04	
Population Density	.2	GRUMP
Household	.2	
<i>Percentage of children under 5 who are underweight</i>	.05	CIESIN
<i>Adult literacy rate</i>	.025	WDI, 2000-2007
<i>Primary school enrollment rate</i>	.025	WDI, 2004-2008
<i>Adjusted infant mortality rate</i>	.025	CIESIN
<i>Life expectancy at birth</i>	.025	WDI, 2006
<i>Total expenditure on health per capita</i>	.025	WDI, 2006
<i>Nursing and midwifery personnel per 10,000 population</i>	.025	WDI, 2002-2006
Governance	.2	
<i>Voice and accountability</i>	.033	WDI, 2008
<i>Political stability and absence of violence</i>	.033	WDI, 1999-2008
<i>Government effectiveness</i>	.033	WDI, 2008
<i>Regulatory quality</i>	.033	WDI, 2008
<i>Rule of law</i>	.033	WDI, 2008
<i>Control of corruption</i>	.033	WDI, 2008

Measuring Resilience to Stress on Water Resources

Due to the large number of international river basins in southern Africa and their existing vulnerability to climate change, this study created an index devoted to water, shown in Figure 6. Rather than trying to measure water scarcity alone as has been done in numerous other studies,¹² the goal of this study was instead to determine which countries in the region are the least prepared to deal with increased pressure on water resources. With the IPCC reports forecasting drastic reductions in rainfall, as well as increases in evaporation and runoff, droughts are expected to become more severe in the region. In turn, variable rainfall on drier land would cause increasingly severe floods, potentially forcing populations to relocate because of flood damage to homes or food insecurity. By measuring infrastructure and hydrological factors in the region, the five indicators in the water resources basket provide a comprehensive assessment of a country's current level of water resource management.

This water basket thus aims to measure two dimensions of water resources: the government's willingness and ability to provide water infrastructure and the availability, use, and origin of water supplies. The percentage of the population with access to improved drinking water and the percentage of cropland that is irrigated is used as a proxy for government commitment to managing water resources. The remaining three indicators are proxies for the availability and use of water resources. Total actual renewable groundwater, the percentage of available freshwater withdrawn annually, and the dependency ratio indicate both a country's existing resources and its ability to withstand drastic changes in rainfall patterns.

Access to an Improved Drinking Water Source

The United Nations' definition of an improved drinking water source is any household piping, public standpipe, borehole, or protected well. Access to an improved drinking water source is defined as the percentage of a country's population with access to one or more of these sources. The data used for this index come from the World Development Indicators.¹³ This indicator uses national data with one data point per country, and in most circumstances there is likely to be considerable local variation within countries. However, the population with access to drinking water is useful to indicate whether or not a country has sufficient water infrastructure and how likely it is able to manage changes in rainfall patterns. If only a small fraction of the population has access to improved water sources, it is likely to rely on standing water or streams for consumption and household use—resources that are more susceptible to changing rainfall patterns.

Table 2a. Percentage of Population with Access to an Improved Water Source

Country	Percentage of Population with Access to an Improved Water Source (%)
Mauritius	100% (continent high)
Botswana	96% (regional high)
Mozambique	42% (regional low)
Somalia	29% (continent low)

Percentage of Cropland Irrigated

Irrigated land is defined as land purposely provided with water, including that which is irrigated by controlled flooding. The percent of cropland irrigated is the amount of irrigated land divided by the sum of all arable land and permanent cropland. The data used in this index come from the World Development Indicators database.¹⁴ This indicator serves as a proxy for infrastructure and the capacity of societies to minimize risk to the food supply and economy in the face of changing rainfall patterns. Because most southern African countries are agrarian economies, the impacts that climate change will have on crop yields are a major concern. If a country has a low level of irrigated cropland, and is therefore reliant on rain-fed agriculture, both its food supply and its economy will suffer from the impacts of climate change relatively more than a country with more extensive irrigation systems.

Table 2b. Percentage of Cropland Irrigated

Country	Percentage of Cropland Irrigated (%)
Egypt	99.94% (continent high)
Madagascar	30.59% (regional high)
Botswana	0.26% (regional low)
Central African Republic	0.10% (continent low)

Total Actual Renewable Groundwater

The total actual renewable groundwater is the total groundwater available in each country. Countries with greater amounts of groundwater are less vulnerable to the short-term effects of climate change because changes in rainfall patterns more slowly impact groundwater sources. The data in this index are yearly averages from the Food and Agricultural Organization's (FAO) AQUAStat database from 2003 to 2007.¹⁵ If a country has plentiful groundwater resources, it is less vulnerable to changing rainfall patterns, because it can offset diminishing surface water sources with groundwater. The potential overuse of groundwater sources by countries in such a position is a problem this paper addresses in the final section.

Table 2c. Total Actual Renewable Groundwater

Country	Total Actual Renewable Groundwater (km ³ /year)
Democratic Republic of Congo	421 (continent high)
Angola	58 (regional high)
Lesotho	0.50 (regional low)
Djibouti	0.02 (continent low)

Percentage of Total Freshwater Withdrawn Annually

The percentage of total freshwater withdrawn is the amount of freshwater withdrawn from a country's total available freshwater in a given country. This indicator is a proxy for the pressure placed on a country's water supply. The data for this indicator are from FAO AQUASTAT database reported between 1998 and 2002. Countries withdrawing large percentages of their available freshwater will have less flexibility should declining rainfall totals cause a reduction in available freshwater. Countries that withdraw small percentages of total available freshwater are less vulnerable because they have unused water supplies, enhancing their ability to manage water shortages.

Table 2d. Percentage of Total Freshwater Withdrawn Annually

Country	Percentage of Total Freshwater Withdrawn Annually (%)
Egypt	94.69% (continent high)
South Africa	24.96% (regional high)
Angola	0.24% (regional low)
Congo	0.01% (continent low)

Dependency Ratio

The dependency ratio is the percentage of total renewable water resources used within one country that originates from outside its borders. This data are also from the FAO AQUASTAT database, calculated using averages from 2003 to 2007. Countries with high dependency ratios are more vulnerable to changing rainfall patterns because of competition for water with neighboring countries. Low dependency ratios imply sufficient in-country water resources for existing consumptive and commercial demands. The ratio is an important indicator, especially given this paper's focus on and concern with transboundary river basins in southern Africa.

Table 2e. Dependency Ratio

Country	Dependency Ratio
Egypt	96.86 (continent high)
Botswana	80.39 (region high)
Lesotho, Madagascar, Angola	0 (region low)
Burkina Faso, Cape Verde, Comoros, Djibouti, Equatorial Guinea, Ethiopia, Gabon, Guinea, Libyan Arab Jamahiriya, Mauritius, Morocco, Rwanda, Sao Tome and Principe, Seychelles, Sierra Leone	0 (continent low)

To ensure that each of the five indicators added a unique attribute to the new basket, researchers tested the correlation of the variables. If any two variables are highly correlated, there is a possibility that the basket would be measuring a condition twice. The results are interesting in two places in particular. Total freshwater withdrawal and the percentage of cropland irrigated have the highest correlation, suggesting that increases in the percentage of water withdrawn are the result of increases in irrigation. This is both an indication that development leads to greater use of natural resources, and that drier countries will be forced to irrigate and to withdraw large percentages of their water.

Table 3: Correlation Test for Resilience to Stress on Water Resources Basket

	Water Access	Dependency Ratio	Total Freshwater Withdrawal	Total Groundwater	Percentage Cropland Irrigated	Final Score
Water Access	1.0000					
Dependency Ratio	-0.0012	1.0000				
Total Freshwater Withdrawal	-0.2065	0.1899	1.0000			
Total Groundwater	-0.3258	0.2827	0.4766	1.0000		
Percentage Cropland Irrigated	0.0483	0.1093	-0.5951	-0.3443	1.0000	
Final Score	0.2196	0.7929	0.4263	0.5241	-0.1003	1.0000

Each of the five indicators in this basket is converted into a percentile rank in relation to the data for each country on the entire continent, and each country's final score is based on the average of these percentile ranks across all five indicators. The final score is then used for final analysis on a country's ability to manage stress on water resources. Each of the five indicators is weighted equally, so unless a country does not have data on one of the indicators, each indicator will be worth 20 percent of the country's score. When a country does not have data for a particular indicator, the average is for the remaining four available data points—meaning that each indicator has an effective weight of 25 percent. There are no cases in which a country has fewer than four out of the five indicators.

Because all the data for the water resources basket are taken at the national level, the result gives a picture of the situation at the country level in the region (Figure 6), but does not pick up on sub-national areas of particular concern. To address this concern, the composite index incorporated sub-national population density and climate-related hazard risk data. These two additional baskets are related to human needs for water (population density) and existing risk for floods, droughts, and other climate-related events (climate-related hazards). The goal of this map is to show the areas of southern Africa that have population centers in which the risk of exposure to climate-related hazards is high and the capacity to manage changes in water resources is low. It is in these areas with which the study is most concerned.

Because continent-wide data are included in index calculations, framing the regional discussion can be difficult. None of the countries in southern Africa lie on either extreme in terms of their continent-wide percentile rank for the water basket. If one were to compare southern African countries with each other, the picture might be quite different, especially given water concerns in the Saharan and Sahel regions. Despite the fact that southern Africa is not necessarily the part of the continent where the least resilience to stress on water resources exists, this basket still tells an important part of the regional story.

The resulting water resilience map of southern Africa (Figure 6) shows the national scores ranging from countries with the least resilience (in brown) to the most resilience (in dark blue). The darker shade of blue indicates that a country is more resilient to stress on water resources. Namibia, Botswana, and Mozambique are vulnerable with respect to their ability to manage increasing stress on water resources. The research confirms this finding, particularly in the cases of Namibia and Mozambique, both of which experience devastating drought-flood cycles and have poor water management capabilities. South Africa's relatively good score with this basket indicates its ability to manage increasing stress on water resources. This outcome does not mean that South Africa has plentiful water resources, only that it has relatively well-developed public infrastructure.

PART 3: FINDINGS

Comparing Composite Maps

Figure 7 shows one of three composite maps of the southern Africa region. This first map is a composite map of three indices: population density, climate-related hazard risk, and resilience to stress on water resources. It shows that the areas of greatest concern are Zimbabwe, Mozambique, Malawi, Lesotho, Swaziland, and the eastern coast of South Africa. These areas show the greatest vulnerability because they have relatively high population densities, display relatively high levels of historical exposure to climate-related hazards, and will be relatively less resilient to increased pressure on water resources. Two major river basins, the Limpopo and Zambezi, cross through eight countries and are subjects of in-depth case studies.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

COMPOSITE VULNERABILITY MEASURED BY THREE EQUALLY WEIGHTED BASKETS

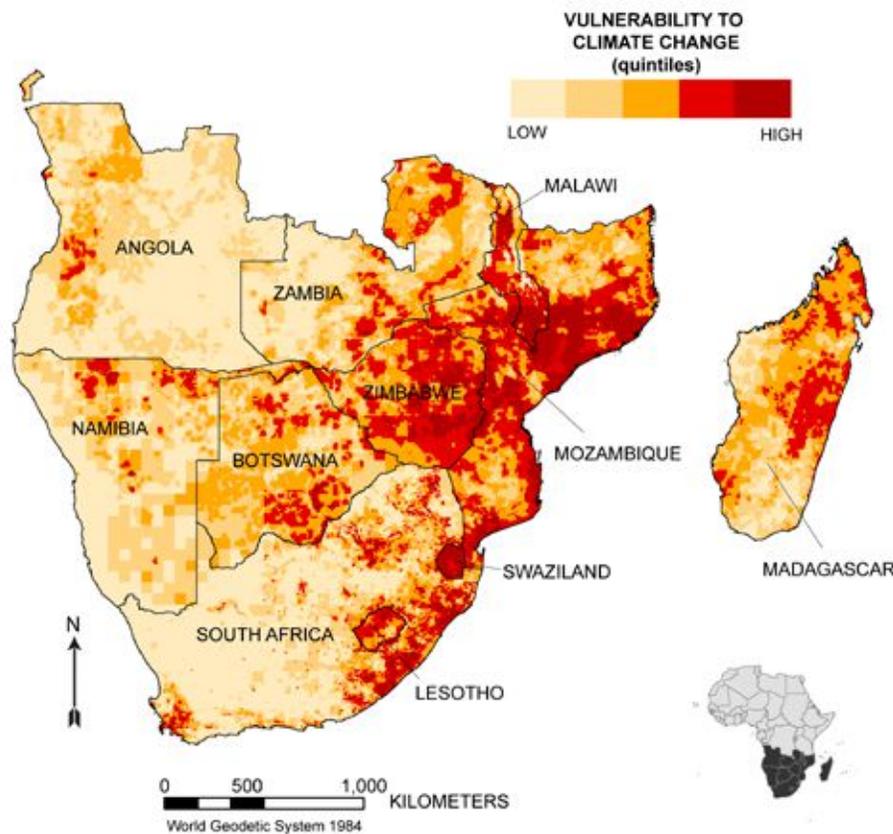


FIGURE 7.
COMPOSITE VULNERABILITY IS MEASURED BY THREE EQUALLY WEIGHTED BASKET INDICATORS:

- RESILIENCE TO STRESS ON WATER RESOURCES (higher resilience, lower vulnerability)
- POPULATION DENSITY (higher population density, greater vulnerability)
- CLIMATE RELATED HAZARDS (higher hazard risks, greater vulnerability)

See Appendix 4 for data sources.

Figure 8 shows four baskets: climate-related hazard risk, population density, resilience to stress on water resources, and governance.

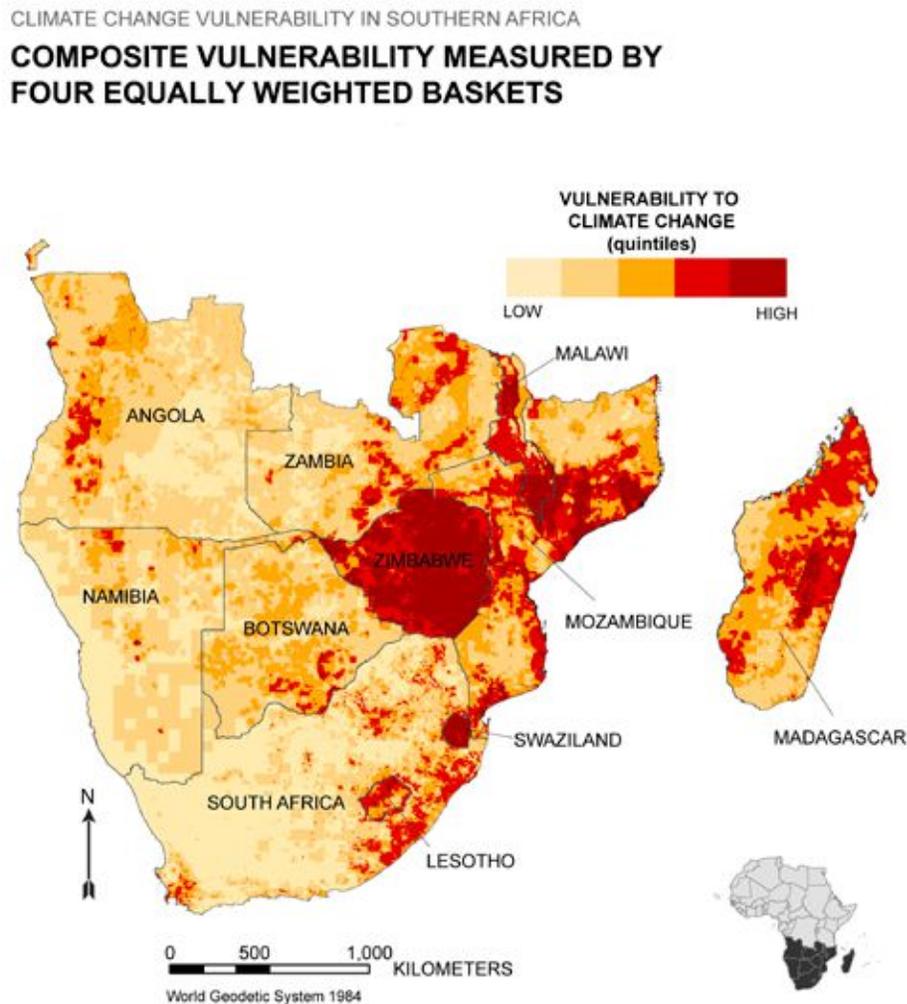


FIGURE 8.
COMPOSITE VULNERABILITY IS MEASURED BY FOUR EQUALLY WEIGHTED BASKETS
 RESILIENCE TO STRESS ON WATER RESOURCES (higher resilience, lower vulnerability)
 POPULATION DENSITY (higher the density, greater vulnerability)
 CLIMATE RELATED HAZARDS (higher hazard risks, greater vulnerability)
 GOVERNANCE (higher level of governance, lower vulnerability)

See Appendix 4 for data sources.

Figure 9 shows all five baskets in this index for southern Africa: climate-related hazard risk, population density, resilience to stress on water resources, household and community vulnerability, and governance.

Figures 8 and 9 generally show the same picture of vulnerability as does Figure 7, which indicates that this focus on water provides a parsimonious model with which to view the entire southern Africa region. In Figure 8, Zimbabwe and Malawi are identified as the most vulnerable places in the region, with parts of Mozambique, Madagascar, and South Africa also registering as more vulnerable. Adding household and community vulnerability in Figure 9 reduces South Africa's overall vulnerability considerably.

By comparing these three maps, it can be concluded that a large part of Zimbabwe’s vulnerability in the total index comes from poor governance, but it is still significantly vulnerable when considering only population, climate-related hazards, and water. South Africa becomes less vulnerable when governance and household vulnerability are added, which might indicate that the government and population are better equipped to deal with climate change.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

COMPOSITE VULNERABILITY MEASURED BY FIVE EQUALLY WEIGHTED BASKETS

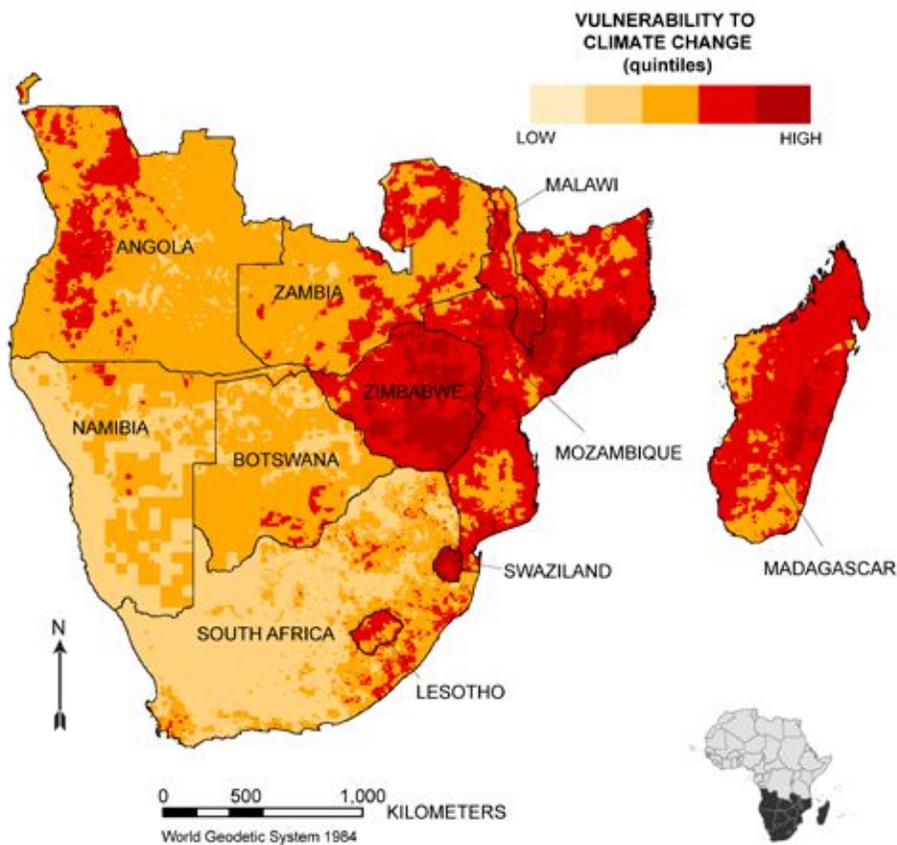


FIGURE 9.
COMPOSITE VULNERABILITY IS MEASURED BY FIVE EQUALLY WEIGHTED BASKETS
 RESILIENCE TO STRESS ON WATER RESOURCES (higher resilience, lower vulnerability)
 POPULATION DENSITY (higher the density, greater vulnerability)
 HISTORICAL EXPOSURE TO CLIMATE RELATED HAZARDS (higher hazard risks, greater vulnerability)
 GOVERNANCE (higher level of governance, lower vulnerability)
 HOUSEHOLD VULNERABILITY
 See Appendix 4 for data sources.

Next, Figure 10 excludes the new water basket to show southern Africa’s vulnerability to climate change with respect only to climate-related hazard risk, population density, household vulnerability, and governance. Comparing Figure 10 with the other composite vulnerability maps indicates that high vulnerability is more widespread than was previously depicted in Figure 9 in two areas of southern Africa: western Angola and Madagascar.

Western Angola's score in the resilience to stress on water resource basket is 0.69, indicating Angola has better resilience to stress on water resources than 69 percent of African countries. This accounts for its improvement in overall vulnerability from Figure 9 compared to Figure 10, which does not include the water basket. It also implies that while Angola is vulnerable to climate change with respect to governance, household, population density, and risk of climate-related hazards, its ability to manage water resources is relatively better than neighboring countries. Based on this analysis, Angola is better equipped to cope with stress on existing water resources. What lessons, if any, can be learned from Angola's apparent ability to manage water supplies are beyond the scope of this paper, but are worthy of future research.

Including the water basket in the overall vulnerability index more closely defines this paper's focus on those areas vulnerable in part because of water-related issues. The most vulnerable portions of Figure 9—the model that includes the water basket—are almost entirely within the Zambezi River basin, an area of focus for one case study in Part 4. The Zambezi basin crosses more borders than any other river basin on the continent and is an area qualitative research identified as extremely vulnerable, especially with respect to water resource management.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

COMPOSITE VULNERABILITY EXCLUDING STRESS ON WATER RESOURCES

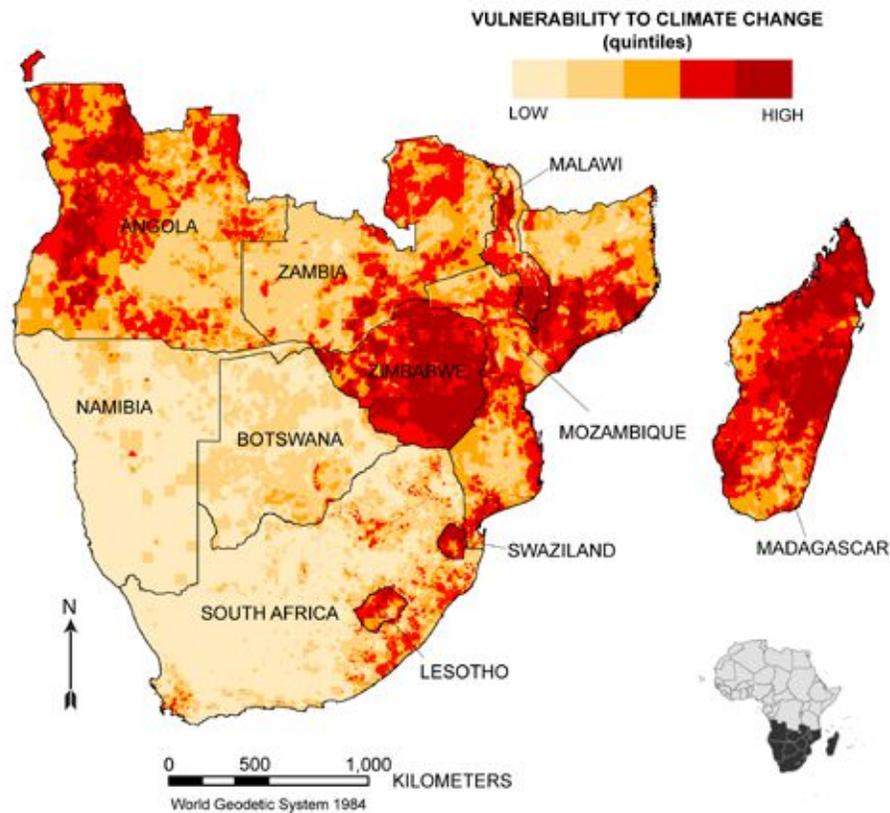


FIGURE 10.

VULNERABILITY IS MEASURED BY FOUR EQUALLY WEIGHTED BASKET INDICATORS

HISTORICAL EXPOSURE TO CLIMATE RELATED HAZARDS (greater hazard risk, greater vulnerability)

GOVERNANCE (better governance, lower vulnerability)

POPULATION DENSITY (higher the density, greater vulnerability)

HOUSEHOLD AND COMMUNITY (greater final score, greater vulnerability)

See Appendix 4 for data sources.

Analyzing Madagascar

The analysis of and experience with creating different vulnerability indices indicates that Madagascar is a difficult country to evaluate in the same context as the rest of southern Africa, particularly considering this paper's focus on water. As an island, it does not depend on other countries for its water resources. Its predominant climate-related hazard risk is cyclones from the Indian Ocean. Madagascar serves as a buffer, rendering the rest of southern Africa less vulnerable to storm surges and cyclone winds. While the island does not appear as vulnerable to climate change with the index formula, this is most likely due to Madagascar's relatively abundant and largely unexploited water supply. It does not face the same water management challenges as countries on the mainland that share river basins and groundwater with multiple neighbors. It is possible that increasing storm surges could contaminate the island's ground and surface water supplies, making water provision more difficult, and this might be cause for further research into water quality in Madagascar.

PART 4: CASE STUDIES

Rationale

After establishing water as an important lens through which to study the effects of climate change in southern Africa, three areas merit further focus: the Limpopo River basin, the Zambezi River basin, and Zimbabwe. The extremely vulnerable portions of southern Africa are mostly contained by one of the two river basins and both are important transboundary water sources in the region. As shown in the table below, both basins are projected to have significant changes in precipitation, evaporation, and runoff in the next century due to climate change. An estimated 10 to 20 percent decrease in precipitation, coupled with a 10 to 25 percent increase in evaporation, would hurt agricultural output in the Zambezi River basin. The significant reduction in estimated runoff indicates that the flow would decrease in the Zambezi as the impacts of climate change worsen. Zimbabwe is the most vulnerable country in the region when all five baskets are included, as shown previously in Figure 6 where the highest level of vulnerability fills most of the country's total land area. Zimbabwe is also vulnerable to changes in both the Limpopo and the Zambezi River basin, because parts of the country lie within each basin.

Table 4: One Hundred Year Estimates of Climate Change Impacts on Water¹⁶

Basin	Change in Precipitation (%)	Change in Potential Evaporation (%)	Change in Runoff (%)
Nile	10	10	0
Niger	10	10	10
Volta	0	4 to -5	0 to -15
Schebéli	-5 to 18	10 to 15	-10 to 40
Zaire	10	10 to 18	10 to 15
Ogooué	-2 to 10	10	-20 to 25
Rufiji	-10 to 10	20	-10 to 10
Zambezi	-10 to -20	10 to 25	-26 to -40
Ruvuma	-10 to 5	25	-30 to -40
Limpopo	-5 to -15	5 to 20	-25 to -35
Orange	-5 to 5	4 to 10	-10 to 10

The Limpopo River Basin

The Limpopo River basin is home to 14 million people in four countries—Botswana, Mozambique, South Africa, and Zimbabwe (Figure 11). The river basin has 2.9 million hectares of harvested crop area, 91 percent of which is rain-fed. The region has on average 50 days of rain per year, occurring mostly between October and August. Current annual rainfall in the basin varies between 200 and 1500 millimeters, with most areas getting less than 500 millimeters each year. Variation between years is particularly hard on agricultural outputs, increasing concerns about food security in the region's dry years. A recent FAO report on climate change in Africa estimated that precipitation in the Limpopo basin will decline by 5 to 15 percent in the next century—making coordinated agricultural and water resource management policies extremely important.¹⁷

Population growth and increasing demands on water resources will exacerbate impacts on the region due to climate change. Competition for water is particularly high in Botswana, where the Limpopo is driest and 60 percent of the population lives within the basin. Each country bordering the Limpopo basin manages water allocation through its own Catchment Area Authority.¹⁸ Despite these organizations, water management is not coordinated and is generally distinct from agriculture planning. This increases the risk that governments will fail to implement sustainable water policy

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

VULNERABILITY TO CLIMATE CHANGE IN THE LIMPOPO RIVER BASIN

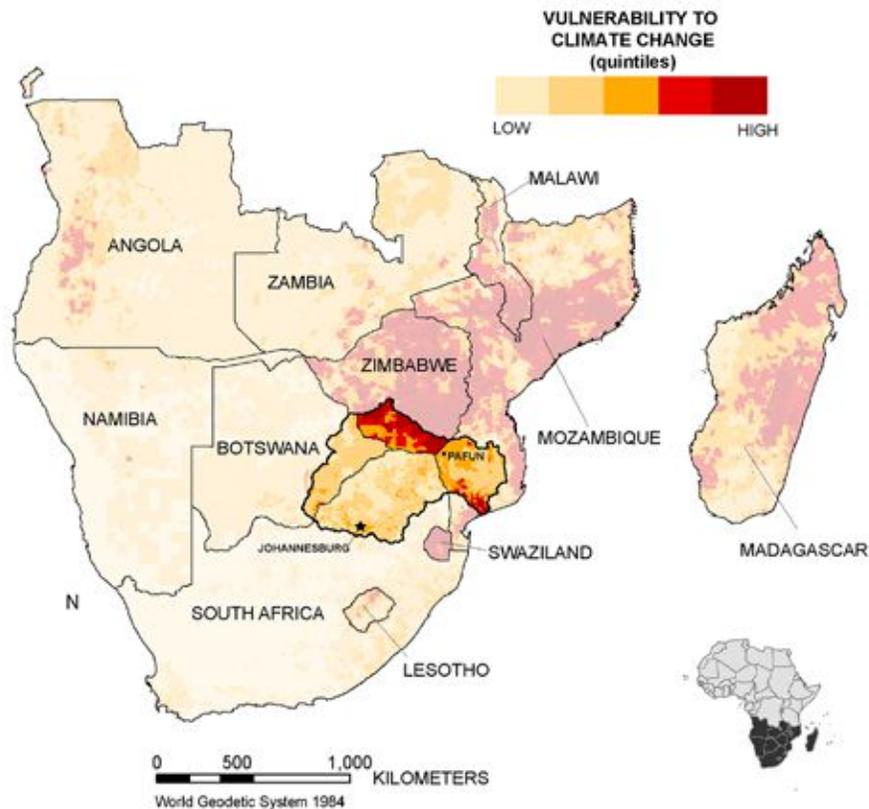


FIGURE 11.
VULNERABILITY IS MEASURED BY FIVE EQUALLY WEIGHTED BASKETS
See Appendix 4 for data sources.

that guarantees long-term access for household use, large-scale commercial users, and farmers. All four countries bordering the basin signed the UN Convention to Combat Desertification (UNCCD), which requires parties to address physical, biological, and socio-economic aspects of drought and desertification, but lacks an effective enforcement mechanism. Because climate change is expected to increase drought severity in the region, large-scale improvements in irrigation efficiency and infrastructure are necessary to manage the impact of declining rainfall totals. However, the region has not taken adequate steps to address these challenges in a coordinated manner.

The Zambezi River Basin

The Zambezi River basin (Figure 12) is the largest river basin in southern Africa. It covers more than 1.37 million square kilometers and is home to 40 million people who rely on its rivers for drinking water, fisheries, irrigation, hydroelectric power, mining, and industry. The headwaters of the Zambezi River begin in Zambia’s Kalene Hills on the Central African Plateau. After crossing seven borders and traveling 3,540 kilometers, the river discharges into the Indian Ocean from its delta in Mozambique. Three of southern Africa’s capitals—Harare, Lusaka, and Lilongwe—

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

VULNERABILITY TO CLIMATE CHANGE IN THE ZAMBEZI RIVER BASIN

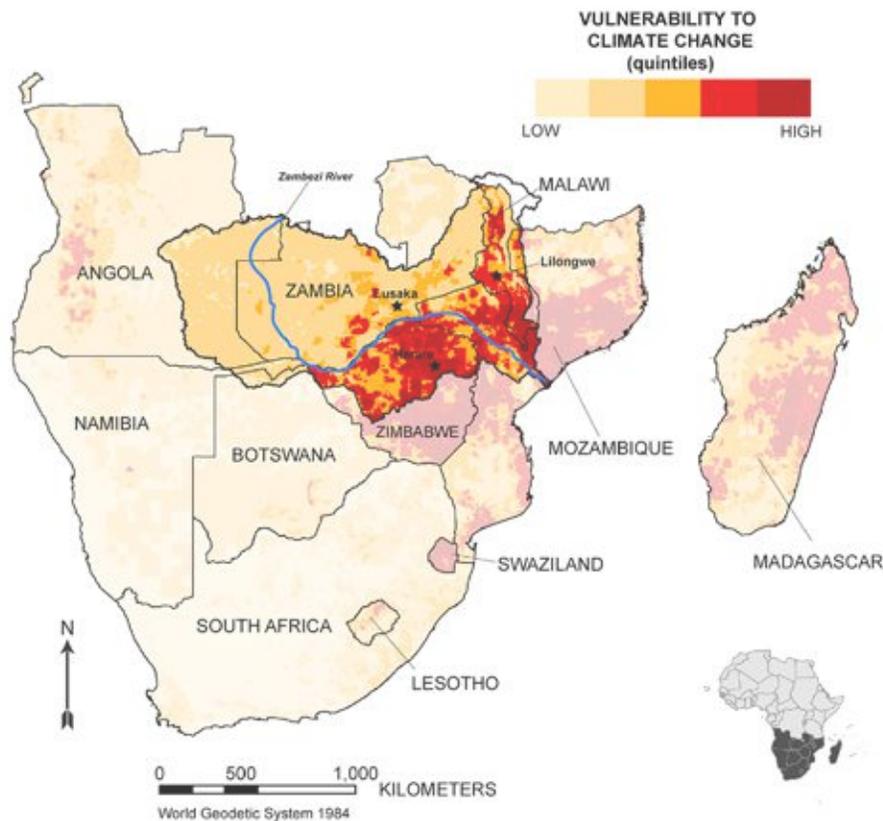


FIGURE 12.
VULNERABILITY IS MEASURED BY FIVE EQUALLY WEIGHTED BASKETS (see Figure 9 for further explanation)
See Appendix 4 for data sources.

lie within the Zambezi basin, making urban water management of particular importance. The Zambezi stretches across eight countries: Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe, and falls within three climate zones: semi-arid, dry sub-humid, and moist sub-humid. The basin's average annual rainfall is between 1,100 and 1,500 millimeters. Much of this precipitation comes between October and April, while the rest of the year remains dry. This seasonal variability in rainfall makes water planning a challenge.

Seasons of extreme drought followed by severe flooding in the Zambezi region are placing extreme stress on water resources. Land dries and hardens during droughts, and the soil cannot absorb the rain that eventually falls, thus causing flash flooding. This flooding, made worse by deforestation in rural areas around the river, displaces hundreds of thousands of people each year and causes soil degradation that hurts agricultural output and exacerbates the following drought.¹⁹ According to 100-year climate projections for the Zambezi River basin from the 2007 IPCC report, significant decreases in precipitation (15 percent), increased evaporative losses (10 to 25 percent), and diminished runoff (30 to 40 percent) are expected. Under these conditions, droughts would become more severe, worsening soil degradation and other flood damage.

While drought threatens the 80 percent of the population dependent on agriculture within the basin, dams on the Zambezi provide an important source of hydroelectric power to Zambia and Mozambique and put additional stress on the basin. Water needed by the citizens of eight countries is used to provide electricity to two, raising concerns about equitable use of shared resources and adding to the complex nature of water management in the basin.

Zimbabwe

Zimbabwe is the most vulnerable country in southern Africa according to this study's model (see Figure 6). Both the Zambezi and Limpopo basins cover portions of Zimbabwe's land area and the country has considerable governance challenges. In August 2008, Zimbabwe was the epicenter of a cholera outbreak that eventually caused 100,000 cases and more than 4,000 deaths.²⁰ The International Federation of Red Cross and Red Crescent Societies blamed the outbreak, which eventually spread south to South Africa, on Zimbabwe's poor water and sanitation infrastructure. Flooding increases the likelihood that people will come in contact with contaminated water and spread water-borne disease.

The Water Act of 1976 was Zimbabwe's first piece of water management legislation. It attempted to control water use and set up a system to allocate resources. It granted all people access to water for consumptive purposes and required all people using water for profit to possess a permanent water right. The Water Court in the capital of Harare distributed water rights on a first-come, first-served basis. The system did not consider groundwater resources or water quality and made it difficult for water rights to change hands or be altered. Revisions to the Water Act in 1998 replaced water rights with water permits that are issued for a limited time, and the renewal of which is subject to water availability. Water is no longer available for private ownership, and stakeholder involvement in decision-making about water use is encouraged. The bill also includes consideration for environmental protection and introduces the "polluter pays" principle.²¹

Despite the seemingly well-laid out water management policies on the books in Zimbabwe, implementation and institution building have been difficult. President Robert Mugabe's priority since 2000 has largely been to transition land owned by white Zimbabweans to black owners. The intense pursuit of this policy by Mugabe and the governing party, the Zimbabwean African National Union – Patriotic Front (ZANU-PF), has left little political will to institute the 1998 water reforms. New owners under the land reform policy have allowed existing wells to run dry and have failed to drill new ones, leaving surrounding communities without adequate water supplies. Prior to the land reform, large industrial farms often provided water for livestock and human consumption in

nearby villages. A lack of sufficient water supplies in the Zimbabwean village of Plumtree, near the Botswanan border, is forcing villagers to seek alternate water sources. Villagers attempting to water their livestock in the river that forms the village's border have been met with derision by their Botswanan neighbors who claim ownership of the river.²²

The importance of the Zimbabwe case is not that it is the most vulnerable country in southern Africa, but that any water management strategy is only as strong as the region's weakest institutions. Zimbabwe is at the center of two key river basins in the region, and any mismanagement of water resources here could impact its neighbors' ability to control and allocate water resources. Regional resource management policy reforms should be made with this consideration in mind, as no region-wide agreement will be successful without universal compliance and effective implementation.

PART 5: IMPLICATIONS FOR WATER MANAGEMENT AND FOOD SECURITY

This study finds that resilience to stress on water resources in southern Africa should be a key focal point, as climate change is likely to yield increasingly variable rainfall and an increasing number of extreme weather events, including severe floods and droughts. There are two important perspectives from which to view the implications of southern Africa's vulnerability to climate change. First, sustainable, equitable, and integrated regional water management policy could be a tool with which southern Africa minimizes the impacts of climate change. Second, the region's food security is increasingly at risk—a situation that will only worsen without implementation of an effective water management policy. This section identifies three key aspects of water management, and the current state of food insecurity in southern Africa's most vulnerable countries, where policy makers could focus their attention.

Cooperation

If the countries of southern Africa are to protect themselves from the extreme effects of climate change, sustainable and coordinated water management policies are necessary. Increasingly severe impacts from climate change and a lack of effective water management practices could send already vulnerable populations into further insecurity and violence. Until recently, most conflict in the Zambezi region has been associated with dam construction. When construction began in Zimbabwe on the Kariba dam in 1960, there was no plan to relocate the 57,000 people whose homes would be flooded after the dam became operational. When the government moved people to a new area, severe water shortages intensified existing anger and riots broke out between police and citizens.²³ In the 1970s, The Cahora Bassa dam project, downstream from Kariba, was a source of conflict because the Front for the Liberation of Mozambique (FRELIMO) claimed the project was an attempt by the Portuguese colonial power to secure influence in the region.²⁴ Conflict over water resources in southern Africa to date has been limited to small-scale local disputes, and a 2006 article suggested that the theory of natural resource scarcity inciting new world wars is "seductive"²⁵; however, the complexity of river basin systems in southern Africa should not be dismissed as a potential source of serious conflict.

The regional SADC Water Protocol lacks enforcement mechanisms and has not led to coordinated multi-lateral agreements between member states. In the Limpopo River basin, long-term water management planning often follows short-term disaster relief. Increasingly, governments are attempting to integrate immediate humanitarian responses to severe floods and droughts into national and regional resource management planning.²⁶ However, relief tends to be concentrated in temporary housing and food aid, rather than the infrastructure development and water allocation reforms that would minimize future disasters.

The Zambezi basin has one functioning management regime—the Zambezi River Authority (ZRA), a bilateral agreement between Zimbabwe and Zambia. The ZRA serves as a limited mandate and provides the legal framework to manage the hydroelectric plants along the Zambezi River.²⁷ The Zambezi Action Plan (ZACPLAN) established a basin-wide commission in 1980 known as the Zambezi Watercourse Commission (ZAMCOM) to promote the equitable and reasonable use of water resources within the basin. Its specific functions are:

to promote, support, coordinate and harmonize the management and development of the water resources of the Zambezi Watercourse [and] advise member states on measures necessary for the avoidance of disputes and assist in the resolution of conflicts among....with regard to the planning, management, utilization, development, protection and conservation of the Zambezi Watercourse (Leonissah, 2004).

ZAMCOM has not succeeded in coordinating water policy across the basin countries. Its stated duties might be the foundation for sustainable water management, yet today it lacks the monitoring capability and enforcement mechanisms that would make it effective.

Inter-basin Transfer and Groundwater

Countries are taking new steps to manipulate available water resources, particularly in the Zambezi basin. River basins are made up of a network of smaller sub-basins. Inter-basin transfer refers to the diversion of water from one sub-basin to another. Several of the eight countries through which the Zambezi flows are planning inter-basin transfer projects to divert water from the river to areas where water is needed either for irrigation or consumptive use.

There are both environmental and socio-economic concerns with such transfers. Inter-basin transfers can cause saltwater intrusion of estuaries, affect migratory fish populations, and permanently damage river ecosystems. In addition, areas that receive transfers often thrive relative to the areas “donating” the water. Recipients of inter-basin waters are often industrializing areas while donors are poorer, unorganized rural populations with little voice in water management decisions. Inter-basin transfers are also legally complicated, particularly when donor rivers cross national borders, because of environmental degradation effects, equity, and sustainability.

South Africa’s increasing commercial demands have raised critique about its ability to balance industrial water use with consumptive use. After 2020, South Africa is expected to withdraw between 2.5 billion and 4 billion cubic meters of water from the Zambezi River each year. Withdrawal at this scale could cause the lowest recorded flow of the Zambezi River at Victoria Falls in Zambia. Water withdrawals from the Zambezi River at this level are unsustainable and could exacerbate existing challenges facing water management institutions in southern Africa.

In addition to increasing demand for water, southern Africa is vulnerable to changing rainfall patterns because of its reliance on groundwater. Groundwater is water beneath the Earth’s surface, often found between saturated soil and rock. In arid to semi-arid regions of southern Africa, people rely heavily on groundwater for drinking water, irrigation, and household use. Approximately 60 percent of the southern Africa region is covered by hard, difficult to drill crystalline rock aquifers.²⁸ Such aquifers can provide only modest water supplies, increasing the importance of responsible water management.

Basement aquifers, or those that begin at least 250 meters below land surface, also provide a growing number of people in the region with water supplies. The Economic Commission for Africa estimates that roughly three-quarters of the African population uses groundwater as its main source of drinking water.²⁹

Groundwater also has an evolving status in southern Africa's political sphere. Before apartheid ended in South Africa, groundwater was the property of whomever accessed and consumed it, either for private or industrial use.³⁰ In 1994, the post-apartheid regime focused on democratizing water policy and forming equitable systems by which to provide water to all of its citizens.

This study concludes that the world's poorest will suffer the greatest from climate change, including those living in southern Africa. Water management issues are inextricably linked to food production and food security. There will be short-term and enduring impacts of cyclic and severe droughts and floods in the region. Shock events, such as the heavy flooding in Mozambique along the Zambezi River delta, can ruin entire harvests quickly. In the long-term, severe droughts followed by heavy rains degrade soil and decrease agricultural productivity. Both the short and long-term impacts of climate change on agriculture threaten to exacerbate already persistent food insecurity in southern Africa.

During Spring 2010, flooding in Mozambique's delta region and severe drought in the country's southern region destroyed crops and added 465,000 people to the already large number of food assistance recipients.³¹ The UN World Food Programme (WFP) predicted in March 2010 that the demand for food assistance would outpace supply. Increasing demand and budget shortfalls prompted the WFP to announce it would reduce rations across southern Africa in an effort to reach as many individuals as possible.³²

Food insecurity is also a serious problem in Zimbabwe. Once considered the "breadbasket" of southern Africa, Zimbabwe exported wheat, tobacco, and corn until 2000. Since then, the country went from food-secure to the number one recipient of WFP aid in southern Africa. Mugabe's land reform program precipitated hyperinflation that destroyed the economy and left citizens without access to basic commodities.³³ As noted previously, land reforms have had significant impact on public infrastructure and water access. A program meant to redistribute white-owned land to black Zimbabweans has indirectly resulted in two devastating problems: poor water resource management and an economic decline so great that the country went from net exporter of wheat to severely food insecure in one decade.

CONCLUSION

By focusing on the importance of water in the southern Africa region, this paper attempts to assess one important piece of the complex, long-term environmental challenge of climate change. *The resilience to stress on water resources* basket in this study indicates an expectation of how effective a country is in planning for, and responding to, one of the impacts of climate change—increasingly unpredictable water supplies. While change in water resources is only one effect of climate change that southern Africa is expected to experience, it is an extremely complicated issue on its own. Transboundary river basins require international agreement, reliable management mechanisms, and governments that balance water allocations for industrial and consumptive use.

This study focused on the processes that make specific parts of southern Africa particularly vulnerable to the impacts of climate change. These findings point to regional cooperation on water management policy as a key way that southern Africa can minimize the impacts of climate change with respect to increasingly variable rainfall, unpredictable rainy seasons, and growing demand for finite resources. Better mechanisms to monitor and evaluate the implementation and enforcement of existing water agreements need to be established and monitored by SADC, the UN, or other regional and international groups.

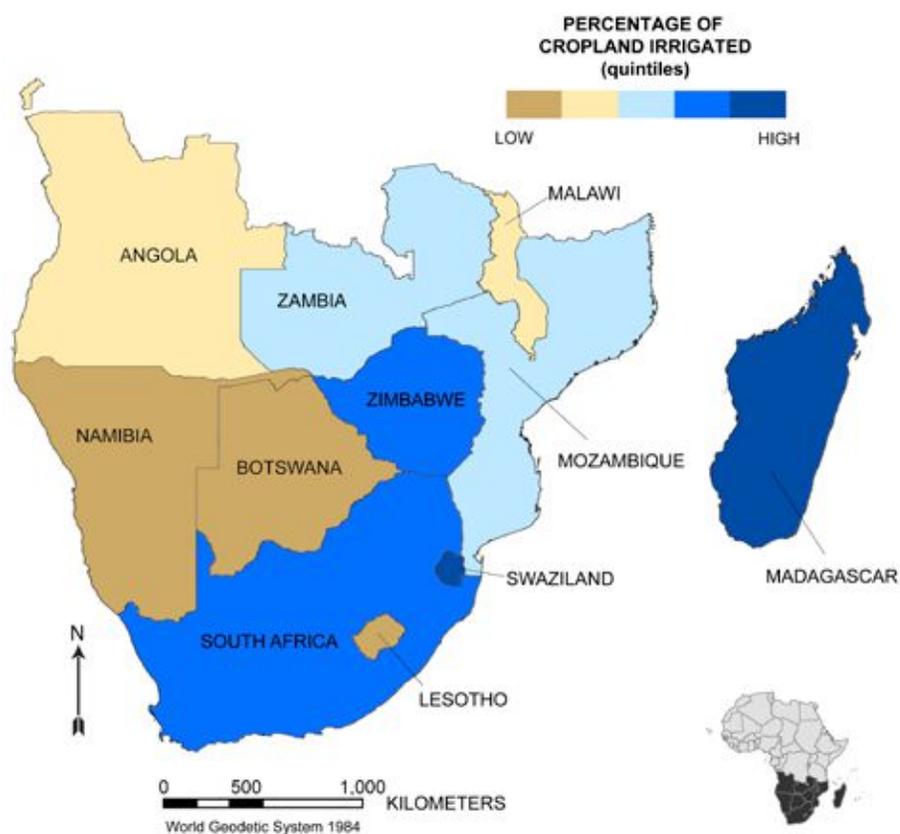
Given the region's inadequate food supply and forecasts that demand for food aid will continue to grow, there is a risk that parts of southern Africa could experience famine. While it is not a certainty that food insecurity will cause regional conflict, such shortages have led to migration, outbreaks of violence, and international intervention in other parts of Africa in the past. Mozambique and Zimbabwe provide clear examples of the two types of food security facing southern Africa in the future. While Mozambique struggles with the shock effects on food supplies from severe flooding in the spring of 2010, Zimbabwe's economic situation places it among the least food secure countries on the continent. The international community has often stepped in to aid countries suffering from famine, and we can only expect calls for our assistance to become more frequent as the impacts of climate change increase.

APPENDICES

Appendix 1. Indicators Comprising the Resilience to Stress on Water Resources Basket

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

PERCENTAGE OF CROPLAND IRRIGATED

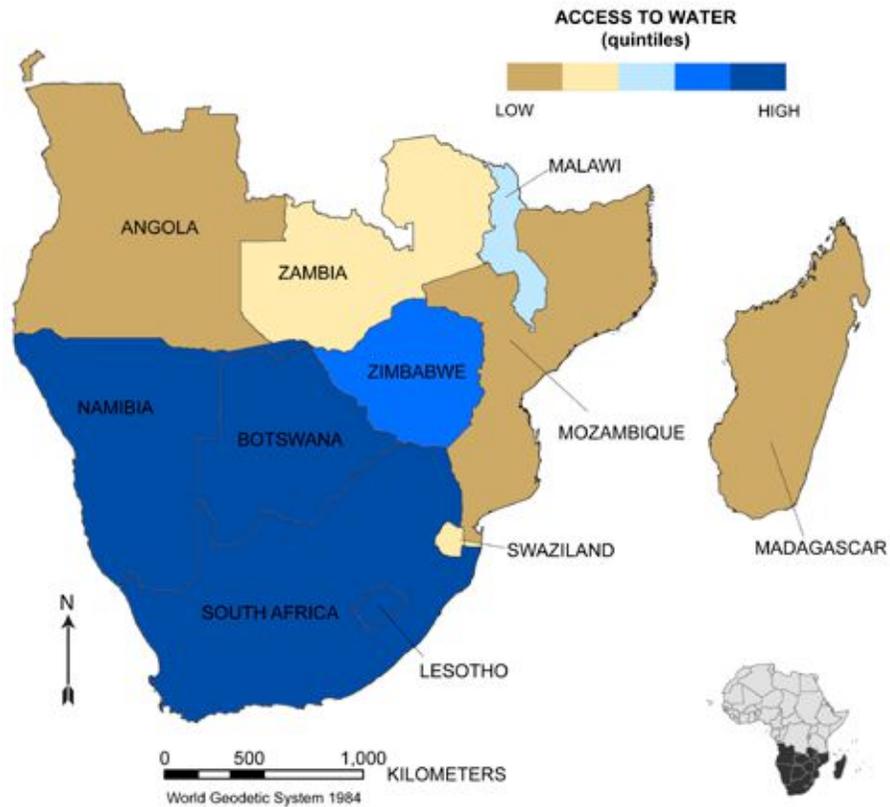


HIGHER PERCENTAGES OF CROPLAND IRRIGATED YIELDS GREATER RESILIENCE TO STRESS ON WATER RESOURCES

Higher percent of cropland irrigated indicates the percent of arable land and permanent cropland purposely provided with water, including controlled flooding.

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

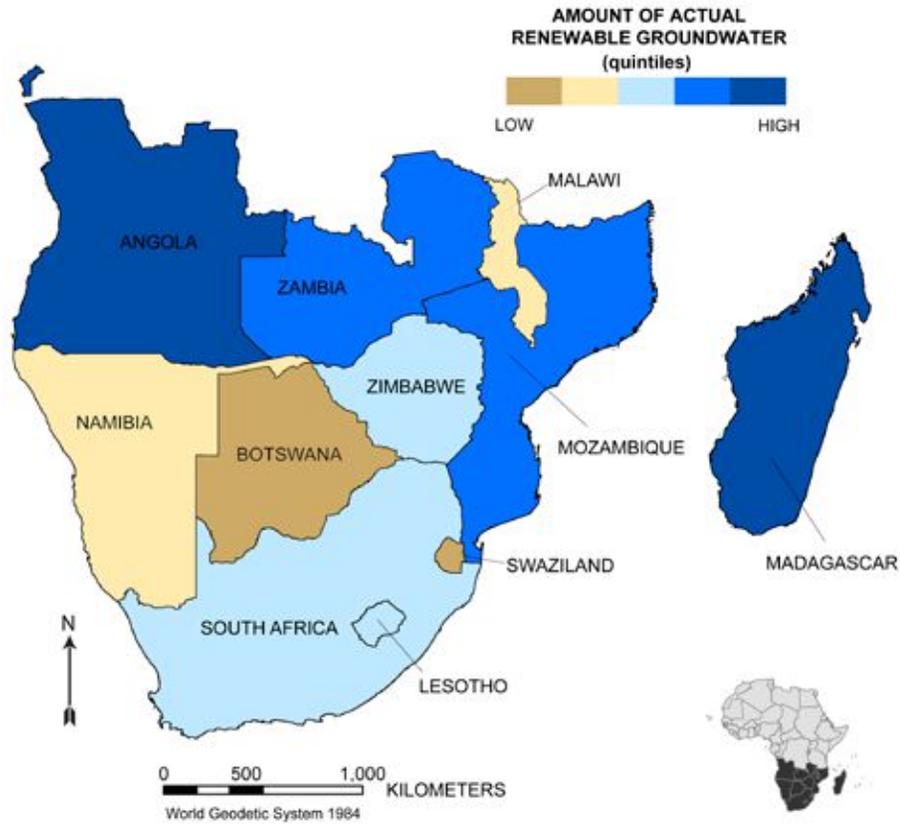
ACCESS TO AN IMPROVED DRINKING WATER SOURCE

HIGHER THE PERCENTAGES OF THE POPULATION WITH ACCESS TO DRINKING WATER YIELDS GREATER RESILIENCE TO STRESS ON WATER RESOURCES.

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

TOTAL ACTUAL RENEWABLE GROUNDWATER

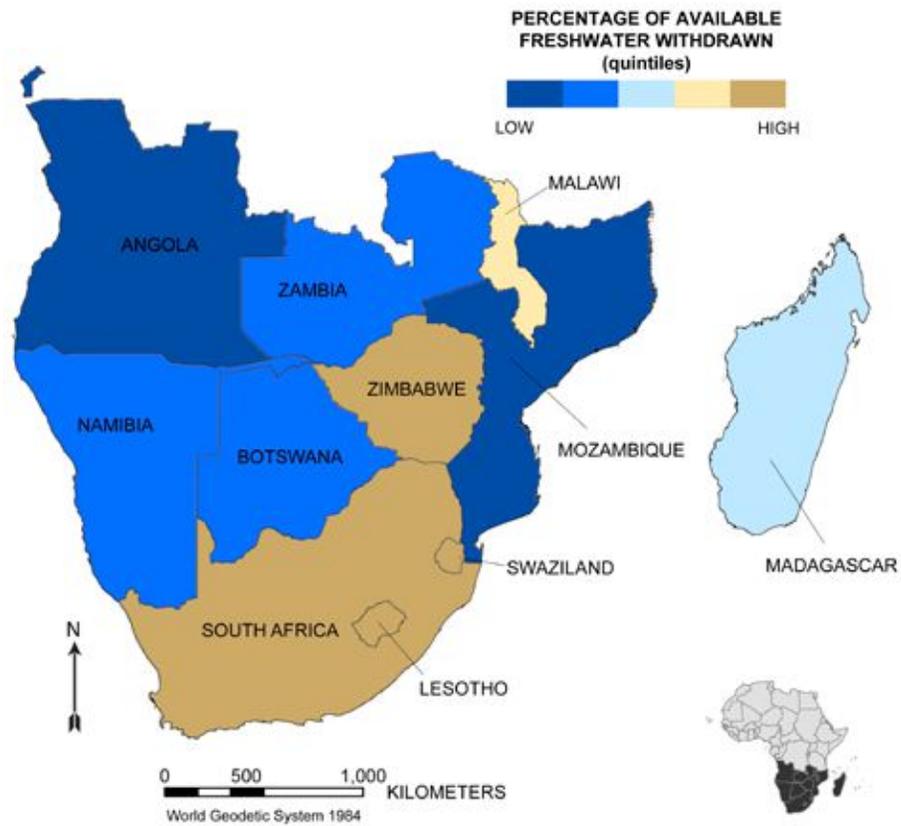


GREATER AMOUNT OF TOTAL ACTUAL RENEWABLE GROUNDWATER YIELDS HIGHER RESILIENCE TO STRESS ON WATER RESOURCES

Total actual renewable groundwater is the sum of the internal renewable groundwater resources and the total external actual renewable groundwater resources.

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

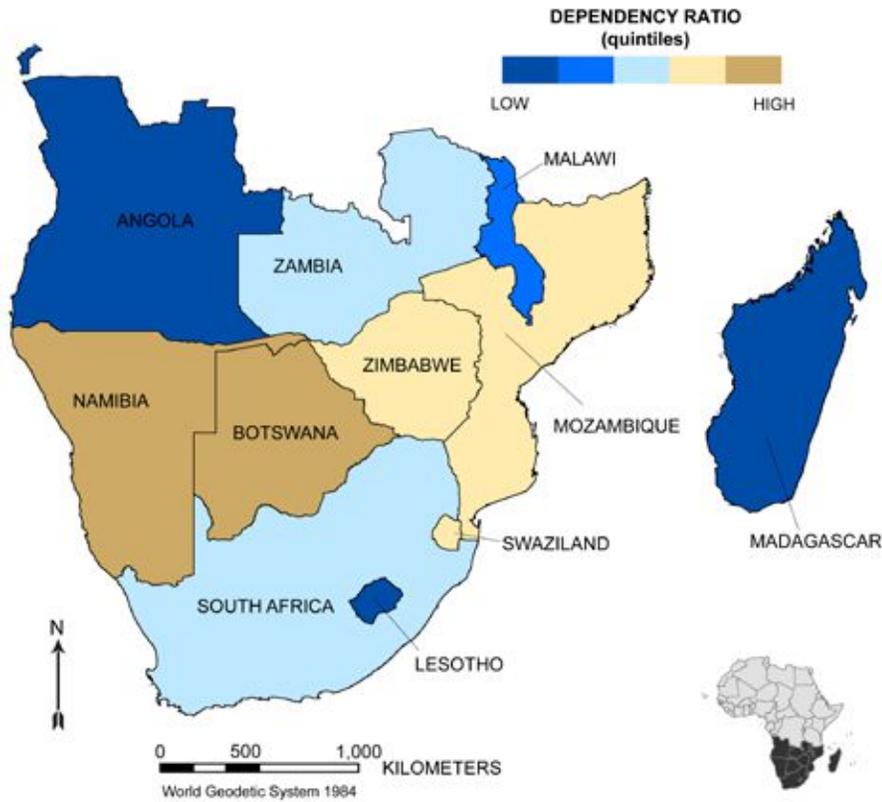
PERCENTAGE OF AVAILABLE FRESHWATER WITHDRAWN**HIGHER PERCENTAGE OF AVAILABLE FRESHWATER WITHDRAWN YIELDS LOWER RESILIENCE TO STRESS ON WATER RESOURCES**

This indicator is a proxy for pressure on water resources.

See Appendix 4 for data sources.

CLIMATE CHANGE VULNERABILITY IN SOUTHERN AFRICA

DEPENDENCY RATIO

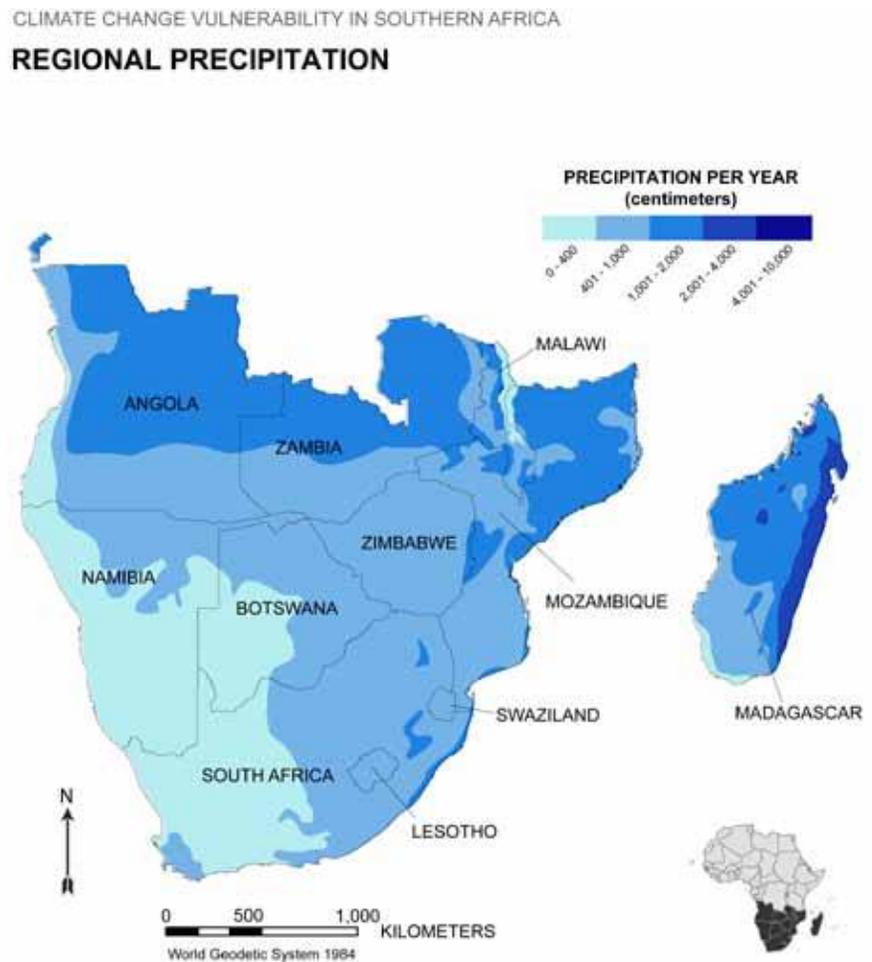


HIGHER DEPENDENCY RATIO YIELDS LOWER RESILIENCE TO STRESS ON WATER RESOURCES

Dependency ratio represents the percent of total renewable water resources originating outside the country. This indicator varies between 0 and 100. A country with a dependency ratio equal to 0 does not receive any water from neighboring countries. A country with a dependency ratio equal to 100 receives all of its renewable water from upstream countries without producing any of its own. This indicator does not consider the possible allocation of water to downstream countries.

See Appendix 4 for data sources.

Appendix 2. Southern Africa Regional Precipitation

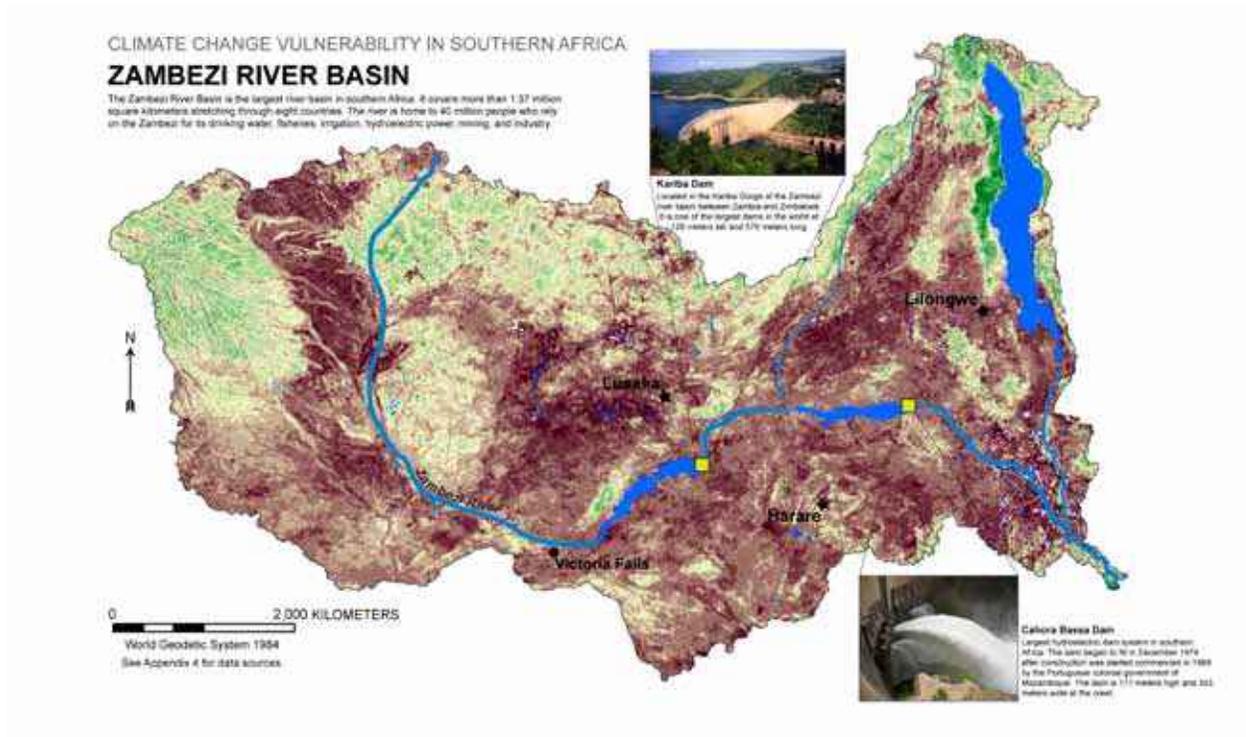


PRECIPITATION IN SOUTHERN AFRICA

High rainfall has been the scenario in many parts of the region, and while this has been a reprieve from the recurrent droughts of recent years for many communities, the heavy rains have also resulted in losses due to flooding for others.

See Appendix 4 for data sources.

Appendix 3. Zambezi River Basin



Appendix 4. Data Sources

Figure 1. Political Boundaries and Geography. Base map elevation image from the U.S. Geological Survey Digital Atlas of Africa, 2000. Administrative boundary data from the World Bank.

Figure 2. Population Density. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Administrative boundary data from the World Bank.

Figure 3. Historical Exposure to Climate-Related Hazards. Climate-related hazard data from the UNEP/GRID Europe, www.preventionweb.net/english/maps. Administrative boundary data from the World Bank.

Figure 4. Household and Community Resilience. Adult literacy rate and primary school enrollment data from the World Bank World Development Indicators. Adjusted infant mortality and percent of children under 5 that are underweight data from CIESIN, http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp#imr. Life expectancy at birth, total expenditure on health per capita, and nursing and midwifery personnel density data from the World Health Organization, www.who.int/whosis/en. Administrative boundary data from the World Bank.

Figure 5. Governance. Governance data from the World Bank Governance Indicators, <http://info.worldbank.org/governance/wgi/index.asp>. Administrative boundary data from the World Bank.

Figure 6. Resilience to Stress on Water Resources. Percent of population with access to improved drinking water data from World Bank World Development Indicators. Dependency ratio, percent of total actual renewable fresh water resources withdrawn, and total groundwater from AQUASTAT, Food and Agriculture Organization, www.fao.org/nr/water/aquastat/main/index.stm. Percent of total cropland irrigated from Nationmaster, www.nationmaster.com/graph/agr_irr_lan_of_cro-agriculture-irrigated-land-of-cropland. Administrative boundaries from World Bank.

Figure 7. Composite Vulnerability Measured by Three Equally Weighted Baskets. Resilience to stress on water resources data from World Bank World Development Indicators; AQUASTAT, Food and Agriculture Organization, www.fao.org/nr/water/aquastat/main/index.stm; Nationmaster, www.nationmaster.com/graph/agr_irr_lan_of_cro-agriculture-irrigated-land-of-cropland. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Climate-related hazard data from the UNEP/GRID Europe, www.preventionweb.net/english/maps.

Figure 8. Composite Vulnerability Measured by Four Equally Weighted Baskets. Resilience to stress on water resources data from World Bank World Development Indicators; AQUASTAT, Food and Agriculture Organization, www.fao.org/nr/water/aquastat/main/index.stm; Nationmaster, www.nationmaster.com/graph/agr_irr_lan_of_cro-agriculture-irrigated-land-of-cropland. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Climate-related hazard data from the UNEP/GRID Europe, www.preventionweb.net/english/maps. Governance data from World Bank Governance Indicators, <http://info.worldbank.org/governance/wgi/index.asp>. Administrative boundary data from the World Bank.

Figure 9. Composite Vulnerability Measured by Five Equally Weighted Baskets. Resilience to stress on water resources data from World Bank World Development Indicators; AQUASTAT, Food and Agriculture Organization, www.fao.org/nr/water/aquastat/main/index.stm; Nationmaster, www.nationmaster.com/graph/agr_irr_lan_of_cro-agriculture-irrigated-land-of-cropland. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Climate-related hazard data from the UNEP/GRID Europe, www.preventionweb.net/english/maps. Governance data from World Bank Governance Indicators, <http://info.worldbank.org/governance/wgi/index.asp>. Household data from World Development Indicators; CIESIN, http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp#imr; World Health Organization, www.who.int/whosis/en. Administrative boundary data from the World Bank.

Figure 10. Composite Vulnerability Excluding Stress on Water Resources. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Climate-related hazard data from the

UNEP/GRID Europe, www.preventionweb.net/english/maps. Governance data from World Bank Governance Indicators, <http://info.worldbank.org/governance/wgi/index.asp>. Household data from World Development Indicators; CIESIN, http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp#imr; World Health Organization, www.who.int/whosis/en. Administrative boundary data from the World Bank.

Figure 11. Vulnerability to Climate Change in the Limpopo River Basin. Resilience to stress on water resources data from World Bank World Development Indicators; AQUASTAT, Food and Agriculture Organization, www.fao.org/nr/water/aquastat/main/index.stm; Nationmaster, www.nationmaster.com/graph/agr_irr_lan_of_cro-agriculture-irrigated-land-of-cropland. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Climate-related hazard data from the UNEP/GRID Europe, www.preventionweb.net/english/maps. Governance data from World Bank Governance Indicators, <http://info.worldbank.org/governance/wgi/index.asp>. Household data from World Development Indicators; CIESIN, http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp#imr; World Health Organization, www.who.int/whosis/en. Administrative boundary data from the World Bank.

Figure 12. Vulnerability to Climate Change in the Zambezi River Basin. Resilience to stress on water resources data from World Bank World Development Indicators; AQUASTAT, Food and Agriculture Organization, www.fao.org/nr/water/aquastat/main/index.stm; Nationmaster, www.nationmaster.com/graph/agr_irr_lan_of_cro-agriculture-irrigated-land-of-cropland. Population density data from UNEP GRID Population Database, <http://na.unep.net/globalpop/africa>. Climate-related hazard data from the UNEP/GRID Europe, www.preventionweb.net/english/maps. Governance data from World Bank Governance Indicators, <http://info.worldbank.org/governance/wgi/index.asp>. Household data from World Development Indicators; CIESIN, http://sedac.ciesin.columbia.edu/povmap/ds_global.jsp#imr; World Health Organization, www.who.int/whosis/en. Administrative boundary data from the World Bank.

Appendix 1. Indicators Comprising the Resilience to Stress on Water Resources Basket. Access to improved drinking water data from World Bank World Development Indicators, 2006. Administrative boundary data from the World Bank. Percent of Cropland Irrigated data from World Bank World Development Indicators, 2003. Total actual renewable groundwater resources data from the Food and Agriculture Organization AQUASTAT, 1998-2002. Percentage of available freshwater withdrawn data from Food and Agriculture Organization AQUASTAT, 2003-2007. Dependency ratio data from Food and Agriculture Organization AQUASTAT, 2003-2007.

Appendix 2. Southern Africa Regional Precipitation. Regional precipitation data from the U.S. Geological Survey Digital Atlas of Africa, 2000. Administrative boundary data from the World Bank.

Appendix 3. Zambezi River Basin. Base map elevation image from the U.S. Geological Survey Digital Atlas of Africa, 2000. Administrative boundary data from the World Bank.

ENDNOTES

- ¹ This graduate student work is based on collaboration with CCAPS researchers as part of a year-long Policy Research Project course at the LBJ School of Public Affairs. The CCAPS program's research in the field of climate security vulnerability is outlined in: Joshua W. Busby, Todd G. Smith, Kaiba L. White, and Shawn M. Strange, *Locating Climate Insecurity: Where are the Most Vulnerable Places in Africa?* (Austin: Robert S. Strauss Center for International Security and Law, 2010).
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- ⁵ Intergovernmental Panel on Climate Change, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. Martin L. Parry et al. (Cambridge: Cambridge University Press, 2007).
- ⁶ "Captivi Flood Victims Faced with Flies, Mosquitos, Contaminated Water," *BBC News*, June 16, 2003.
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- ¹¹ Appendix 1 includes maps showing each indicator in the basket on resilience to stress on water resources.
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- ¹³ The World Bank, *World Development Indicators* (Washington: The World Bank, 2010).
- ¹⁴ Ibid.
- ¹⁵ The Food and Agriculture Organization's AQUASTAT is a collection of water resource data from national sources that is systematically reviewed to ensure consistency of definitions. Its methodology is intended to provide a complete and consistent water resource database by harmonizing available databases. A comparative analysis of the data is conducted at regular intervals from which AQUASTAT reports its best estimate for available water levels in each country. Data for three of the five indicators in the *resilience to stress on water resources* basket are from the AQUASTAT database: total actual renewable groundwater, percentage of total freshwater withdrawn, and the dependency ratio.
- ¹⁶ Intergovernmental Panel on Climate Change, *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, ed. James J. McCarthy et al. (Cambridge: Cambridge University Press, 2001).
- ¹⁷ Tingju Zhu and Claudia Ringler, *Climate Change Implications for Water Resources in the Limpopo River Basin* (Washington: International Food Policy Research Institute, 2010).
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- ²¹ Hodson Makurira and M. Mugumo, "Water Sector Reforms in Zimbabwe: The Importance of Policy and Institutional Coordination on implementation" (Paper presented at the proceedings of the African Workshop, Nairobi, Kenya, October 8-10, 2003).
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- ²⁶ Food and Agricultural Organization of the United Nations Subregional Office for Southern and East Africa, *Drought impact mitigation and prevention in the Limpopo River Basin* (Rome: Food and Agricultural Organization of the United Nations, 2004).
- ²⁷ M. Tumbare and C. Mukosa, "A Brief History of the Creation of the Zambezi River Authority" (Paper presented at the Conference on Water Resources, Policy, and Assessment, Addis Ababa, Ethiopia, March 20-25, 1995).
- ²⁸ Federal Institute for Geosciences and Natural Resources, Cap-Net, WA-Net, and WaterNet, *Capacity Building for Groundwater Management in West and Southern Africa* (Hanover: Federal Institute for Geosciences and Natural Resources, 2007).
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