Climate Change and Insecurity: Mapping Vulnerability in Africa

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Climate Change and Insecurity

Mapping Vulnerability in Africa

Joshua W. Busby, Todd G. Smith, Kaiba L. White, and Shawn M. Strange

As floods displaced millions in Pakistan in August 2010, half a world away the Sahelian nation of Niger, notable to the outside world as the producer of about 8 percent of the world's uranium, was experiencing its own devastating floods. In the wake of crippling droughts, Niger's floods displaced 200,000 and left nearly 8 million people, more than half the country's population, at risk of starvation.[1] The cycle of droughts and floods, which affected Niger and parts of neighboring Chad and Mali, was regarded as unusual, though scientists could not ascertain whether it was a function of normal variation or was exacerbated by anthropogenic climate change.[2] As in Pakistan, the militaries in these countries were mobilized for humanitarian relief. Military aircraft from Algeria and France flew in humanitarian supplies while civilian nongovernmental organizations and United Nations organizations did their best to meet the needs of Niger's populace. Niger was also beset by other problems. In February 2010, the

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1. Andrew Johnson, "Millions at Risk as Crops Fail in Central Africa," *Independent* (London), August 29, 2010, http://www.independent.co.uk/news/world/africa/millions-at-risk-as-crops-fail-in-central-africa-2064802.html; Norweigan Council for Africa (NCA), "Niger: Getting Food in by Truck, Boat, Camel, and Cart" (Oslo: NCA, August 17, 2010), http://www.afrika.no/Detailed/19775.html; and Mike Thomson, "Audio Slideshow: Niger's Double Disaster," British Broadcasting Corporation, August 30, 2010, http://www.bbc.co.uk/news/world-11099798.
2. "In-Depth: Food and Nutrition Crisis in Niger and the Western Sahel," IRIN, June 21, 2007, http://www.irinnews.org/IndepthMain.aspx?InDepthID=81&ReportID=72869.

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military seized power in a coup, displacing the country's longtime leader, Mamadou Tandja, who had sought to amend the constitution and retain power.[3] Even as Niger's interim military government grappled with the floods, seven foreigners, including five French nationals, were kidnapped in the uranium mining region in September 2010 by groups affiliated with al-Qaida in the Islamic Maghreb, leading the French government to encourage its 1,700 nationals to leave the country.[4] By 2012, adverse weather conditions and political instability had gripped more of the region as the World Food Programme warned of a looming food crisis across the Sahel, and neighboring Mali experienced a coup and a breakaway secessionist movement. Niger's situation in 2010, similar to Pakistan's, was one of devastating storms competing for attention and resources in a country beset by other ongoing security concerns. These episodes illustrate an emerging security challenge likely associated with climate change, where large numbers of people are put at risk of death from climate-related hazards while their governments lack either the will or the capacity to protect them.

Which parts of Africa are most vulnerable to the security consequences of climate change? The challenges posed by climate change are not uniformly distributed within the continent. To identify areas of security vulnerability and to prioritize limited resources, one cannot say "Ethiopia is vulnerable" without explaining which parts of Ethiopia are particularly vulnerable and why. 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 can prioritize their scarce resources, and the international community can better target adaptation assistance. Climate vulnerability studies are becoming increasingly important as countries recognize that the findings could have significant implications for resource allocation.[5]

Can scholars of security studies, who typically seek to explain past patterns of conflict and violence, offer any insights into how to identify areas of potential concern? By coupling innovative geospatial mapping techniques with

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3. David Smith, "Military Junta Seizes Power in Niger Coup," *Guardian* (London), February 19, 2010, http://www.guardian.co.uk/world/2010/feb/19/niger-military-junta-coup.
4. Reuters, "Five French Said Kidnapped in Niger," September 16, 2010, http://www.reuters.com/article/2010/09/16/oukwd-uk-niger-french-idAFTRE68F1JX20100916?feedType=RSS&feedName=worldNews&utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+reuters%2FAFRICAWorldNews+(News+%2F+AFRICA+%2F+World+News); and Reuters, "Niger: France Urges Citizens to Leave Mining Region," *New York Times*, September 18, 2010, http://www.nytimes.com/2010/09/18/world/africa/18briefs-Niger.html?_r=1&emc=eta1.
5. Lisa Friedman, "Which Nations Are Most Vulnerable to Climate Change? The Daunting Politics of Choosing," *New York Times*, February 24, 2010, http://www.nytimes.com/cwire/2011/02/24/24climatewire-which-nations-are-most-vulnerable-to-climate-95690.html?ref=energy-environment.

insights about governance and political violence, we have developed an approach to map subnational security vulnerability to climate change, which we define as situations in which large numbers of people are put at risk of mass death as a result of exposure to climate-related phenomena. In this project, we use geographic information systems (GIS) to locate climate security vulnerability in Africa. GIS allows users to visualize data to calculate spatial properties of locations or geographic shapes (e.g., states, provinces, or subnational administrative units). Although GIS is not widely deployed in international relations, it is used extensively in other fields and can provide a useful complement to the scholar's toolkit.

Since 2005, a host of studies, largely from think tanks, advocates, and the broader policy community, have identified climate security concerns as a distinct issue, with weather-related effects of climate change—droughts, floods, storms—contributing to dislocation, migration, and competition over scarce resources, and, in turn, functioning as a "threat multiplier" that could increase the risks of conflict and even state failure.[6] This gray literature has begun to offer recommendations even as the scholarly community questions whether or not climate change is associated with the increased likelihood of civil conflict.

Most of the scholarly work in this arena relies on quantitative data on historic rainfall, drought, and storm patterns, and seeks to ascertain whether climate phenomena are correlated with the increased frequency or onset of violent conflict, controlling for other factors. By focusing on the links between climate change and conflict, the academic community has narrowed its conception of security to lose sight of more pressing and imminent threats posed by extreme weather events. Such events already pose a security challenge for which both national governments and the international community need to prepare. Extreme weather events—such as Hurricane Katrina, Cyclone Nargis, Pakistan's floods of 2010, Australia's of 2011, and Hurricane Sandy in 2012—are requiring the mobilization of militaries for humanitarian relief.[7] If scientists

6. CNA Corporation, "National Security and the Threat of Climate Change" (Alexandria, Va.: CNA, 2007), http://www.cna.org/reports/climate.
7. Scientists continue to debate whether anthropogenic climate change had anything to do with these events. They cannot attribute a single extreme weather event to climate change, but they increasingly say that climate change makes such events more likely. Large concentrations of people and infrastructure on coasts or along rivers in environmentally degraded locations indubitably transformed such weather episodes into human disasters. Even if the science of attribution of specific events remains unsettled and the likely regional consequences of climate change remain uncertain, the expectations in the aggregate are clear: climate change should yield a world of more extreme weather. Anil Ananthaswamy, "Time to Blame Climate Change for Extreme Weather?" *New Scientist*, August 25, 2010, http://www.newscientist.com/article/mg20727754.200-time-to-blame-climate-change-for-extreme-weather.html; Judith Curry, "Attribution of Extreme Events," *Climate Etc.*, blog, January 15, 2011, http://judithcurry.com/; Roger Pielke Jr., "Signals of Anthropogenic Climate Change in Disaster Data," *Science, Innovation, Politics*, blog, January 4, 2011, http://

are right that climate change will likely deliver more frequent and perhaps more severe events such as these,[8] then governments will increasingly have to divert attention and resources from other national security priorities, including protecting the homeland from internal or external threats and, for those nations at war, from urgent warfighting efforts.

Our approach is based on the recognition that security vulnerability is about more than physical exposure to climate-related hazards and includes other demographic, household, and political sources of vulnerability. We start by mapping physical exposure to climate-related hazards including droughts, floods, storms, wildfires, and low-elevation coastal zones. We then examine population density, recognizing that from a climate security perspective these physical hazards matter more where large numbers of people live. Next, we bring in a basket of household resilience indicators, mindful that the first line of defense for communities is the resources they have to protect themselves. Finally, we acknowledge that whether or not a climate hazard becomes a full-blown disaster may depend on whether their governments are willing or able to protect them. Adding together these four baskets of vulnerability—physical, demographic, household, and governance, we create a composite index of subnational climate security vulnerability. These baskets initially receive equal weight in the index, though we later relax these assumptions.[9]

Because the physical exposure data were in a format of digitized pixel points, or rasters, we begin by spatially mapping the confluence of physical exposure with the other elements of vulnerability. As we discuss in the online statistical appendix, data limitations made it difficult to test the validity of the composite index through traditional econometric approaches. As a consequence, we explore a variety of other measures in this article to validate our findings, including sensitivity analysis and extensive fieldwork.

This study captures a static snapshot of chronic vulnerability, rather than emergent, dynamic vulnerability.[10] Other organizations, such as the World Food Programme and the United Nations Food and Agricultural Organization, have

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rogerpielkejr.blogspot.com/; and Claudia Tebaldi, "Pushing the Envelope of Climate Science 'Attribution Studies,'" *Climate Central*, blog, August 20, 2010, http://www.climatecentral .org/blog/.

8. Intergovernmental Panel on Climate Change (IPCC), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)*, Christopher B. Field, Vicente Barros, Thomas F. Stocker, Qin Dahe, David Jon Dokken, Kristie L. Ebi, Michael D. Mastrandrea, Katharine J. Mach, Gian.-Kasper Plattner, Simon K. Allen, Melinda Tignor, and Pauline M. Midgley, eds. (New York: Cambridge University Press, 2012), http://ipcc-wg2.gov/SREX/.

9. This approach largely mirrors a recent effort to map subnational conflict risk in Asia. See Aas Rustad, Siri Camilla, Halvard Buhaug, Åshild Falch, and Scott Gates, "All Conflict Is Local: Modeling Sub-National Variation in Civil Conflict Risk," *Conflict Management and Peace Science*, Vol. 28, No. 1 (February 2011), pp. 15–40.

10. Jericho Burg, "Measuring Populations' Vulnerabilities for Famine and Food Security Interven-

parallel efforts to document and map emergent vulnerability to drought and famines.[11] Our approach offers a way to identify "hot spots" of concern at a subnational level, enabling scholars to focus on these areas for further case study investigation and national governments and the international community to prioritize resources accordingly. Given Africa's particular vulnerability to climate change and its rising strategic significance as a security concern as well as a potential market, this article is especially timely.

Our approach ranks locations within Africa in terms of their relative security vulnerability to climate change. The vulnerability rankings are relative to other African countries rather than to 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. We find that the areas in Africa with the greatest vulnerability are parts of the Democratic Republic of the Congo (DRC), Guinea, Sierra Leone, Somalia, and South Sudan. Some areas that face high physical exposure to climate change, such as North African countries along the Mediterranean, appear less vulnerable, given their higher levels of community and household resilience and their generally more capable though—as the 2011 political transformation in North Africa attests—far from wholly democratic and stable governance. By contrast, other countries in Africa, with less physical exposure to climate change, such as Niger, Somalia, and South Sudan, appear more vulnerable when we bring in resilience and governance. Given data limitations, our findings are provisional. We employ this mapping technique continent-wide for Africa, offering this approach as a "proof-of-concept" for further refinement as more subnational data and other indicators become available.

In the first section, we explain the reasons for choosing Africa and why our approach focuses on security outcomes. In the second section, we examine the concept of vulnerability. In the third section, we introduce our approach. The fourth section reviews our findings, and a fifth section identifies areas for future research.

Why Africa? Why Security?

Along with Asia, Africa is widely recognized as one of the continents most vulnerable to climate change. Africa's vulnerability is partly driven by unfortunate geography, where the physical effects of climate change are likely to be among

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tions: The Case of Ethiopia's Chronic Vulnerability Index," *Disasters*, Vol. 32, No. 4 (December 2008), pp. 609–630.
11. World Food Programme (WFP), *Climate and Disaster Risk Solutions* (Rome: WFP, 2009).

the most severe on the planet. It is also largely the result of the low adaptive capacity of many African states, which is a product of problems in their economies, health-care and education systems, infrastructure, and governance.[12]

According to the EM-DAT International Disaster database, from 1999 to 2010, climate-related weather "disasters" in Africa killed nearly 13,000 people, made homeless 2.8 million, and affected on the order of 187 million people overall.[13] Although a number of high-profile disasters during this period were located outside Africa—such as the 2004 Asian tsunami, the 2010 Haitian earthquake, and the 2010 Pakistani floods—Africa typically receives a large percentage of resources from bilateral donors and the international community for disaster assistance. Between fiscal years 2000 and 2009, the U.S. government allocated more than 58 percent of its total humanitarian funding for disasters to Africa, with a significant share of these funds dedicated to Ethiopia, Somalia, and Sudan.[14]

Africa has become increasingly important vis-à-vis the rest of the world, though its strategic importance still pales compared with other regions. The series of revolts that began in Tunisia in December 2010 elevated North Africa's importance in the eyes of the international community. Even before these

12. Reid Basher and Sálvano Briceño, "Climate and Disaster Risk Reduction in Africa," in Pak Sum Low, ed., *Climate Change and Africa* (Cambridge: Cambridge University Press, 2005), pp. 269–281; M. Boko, I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, and P. Yanda, "Africa," in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds., *Climate Change 2007: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007), pp. 433–467; Paul Collier, Gordon Conway, and Tony Venables, "Climate Change and Africa," *Oxford Review of Economic Policy*, Vol. 24, No. 2 (Summer 2008), pp. 337–353; Jay Gulledge, *Scientific Uncertainty and Africa's Susceptibility to Climate-Driven Conflict* (Washington, D.C.: Pew Center on Global Climate Change, 2008); and Low, *Climate Change and Africa*.

13. These disasters included droughts, floods, storms, wet landslides, and wildfires. Centre for Research on the Epidemiology of Disasters (CRED), "EM-DAT: The OFDA/CRED International Disaster Database," 2011, www.emdat.be.

14. United States Agency for International Development, Office of Foreign Disaster Assistance (USAID-OFDA), *USAID-OFDA and USG Disaster Response, FY 2000–2009* (Washington, D.C.: USAID, 2010). This represents $14.6 billion of $25.3 billion in estimated U.S. government expenditures between fiscal years (FY) 2000 and 2009 (constant 2009 $). Within that total, 65 percent of USAID-OFDA's funding was spent in Africa (about $2.45 billion of $3.8 billion in constant 2009 $). Those expenditures include spending on complex emergencies, particularly for Darfur (which may have some relation to historic drought conditions). Exclusively climate-related disasters accounted for about 12 percent of OFDA's total (excluding complex emergencies but including floods, droughts, fires, winter emergencies, typhoons, and food security). The Department of Defense (DoD) assists in about 10 percent of the overseas disaster emergencies. Between FY 2005 and 2010, the Joint Staff in the DoD estimated that the DoD assisted in thirty disasters, twenty-one of which were weather-related, though only one of which was in Africa (the Algerian floods of FY 2006). This estimate does not include, however, additional efforts by Combatant Commands. Office of Partnership Strategy and Stability Operations (PSO), "DoD Involvement in Foreign Disaster Relief, 2005–2010" (Washington, D.C.: PSO, 2010).

events, recognition of Africa's rising strategic importance led the U.S. military to create a new geographic combatant command for Africa in 2007. Among the reasons for this more strategic interest are rising oil exports from Algeria, Angola, Libya, Nigeria, and other countries, which make African stability important for oil importers. In addition, the fragility of a number of African states and the potential for wider conflagration from spillovers of refugees and conflict remain constant concerns to the international community.[15] As Halvard Buhaug, Nils Petter Gleditsch, and Ole Magnus Theisen have noted, Africa is one of the world's remaining zones for intrastate conflict: the "shatter belt" of conflict-prone states includes two bands in the Horn of Africa and the Great Lakes region and an area from the Caucasus to the Philippines.[16] The belt is home to Somalia's pirates, who have become more than a nuisance for international commerce. It also encompasses Sudan, which celebrated a tenuous peaceful dissolution into two states in 2011 when the South voted for secession, and which currently threatens to descend into interstate war. State weakness and the presence of incipient terrorist operations under the al-Qaida franchise have also attracted Western attention. Even as chronic problems of governance in Africa have consumed the attention of many Western donors, other actors and countries—notably the Chinese—see great opportunity for resource acquisition and the potential for markets as a number of African countries experience high economic growth.

Our project is located in the larger, emergent debate about climate change and security.[17] Concerns about climate and security are a natural successor to the literature on environmental security from the 1990s, pioneered by Thomas

15. Anthony Lake and Christine Todd Whitman, "More Than Humanitarianism: A Strategic U.S. Approach toward Africa," Independent Task Force Report, No. 56 (New York: Council on Foreign Relations, 2006), http://www.cfr.org/publication/9302/more_than_humanitarianism.html; and Letitia Lawson, "U.S. Africa Policy since the Cold War," *Strategic Insights*, Vol. 6, No. 1 (January 2007), http://www.ccc.nps.navy.mil/si/2007/Jan/lawsonJan07.pdf.
16. Halvard Buhaug, Nils Petter Gleditsch, and Ole Magnus Theisen, "Implications of Climate Change for Armed Conflict" (Washington, D.C.: Social Development Department, World Bank, 2008), http://siteresources.worldbank.org/INTRANETSOCIALDEVELOPMENT/Resources/SDCCWorkingPaper_Conflict.pdf.
17. Nils Petter Gleditsch, Ragnhild Nordås, and Idean Salehyan, "Climate Change and Conflict: The Migration Link," Coping with Crisis: Working Paper Series (New York: International Peace Academy, 2007), http://www.ipacademy.org/asset/file/169/CWC_Working_Paper_Climate_Change.pdf; Ragnhild Nordås and Nils Petter Gleditsch, "IPCC and the Climate-Conflict Nexus," paper presented at the International Studies Association Convention, New York City, New York, February 15–18, 2009; Clionadh Raleigh, Lisa Jordan, and Idean Salehyan, "Assessing the Impact of Climate Change on Migration and Conflict" (Washington, D.C.: Social Development Department, World Bank, 2008), http://siteresources.worldbank.org/EXTSOCIALDEVELOPMENT/Resources/SDCCWorkingPaper_MigrationandConflict.pdf; and Idean Salehyan, "From Climate Change to Conflict? No Consensus Yet," *Journal of Peace Research*, Vol. 45, No. 3 (May 2008), pp. 315–332.

Homer-Dixon among others.[18] Similar to work on environmental security, the literature on the "securitization" of climate change in the policy world and among academics has largely focused on the causal connections between climate change and violent conflict.[19] 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 correlate historically with the onset of violent conflict.[20] To date, the findings of this literature

18. Thomas F. Homer-Dixon, *Environment, Scarcity, and Violence* (Princeton, N.J.: Princeton University Press, 1999); Colin H. Kahl, *States, Scarcity, and Civil Strife in the Developing World* (Princeton, N.J.: Princeton University Press, 2006); Colin H. Kahl, "Population Growth, Environmental Degradation, and State-Sponsored Violence: The Case of Kenya, 1991–93," *International Security*, Vol. 23, No. 2 (Fall 1998), pp. 80–119; Marc A. Levy, "Is the Environment a National Security Issue?" *International Security*, Vol. 20, No. 2 (Fall 1995), pp. 35–62; Val Percival and Thomas Homer-Dixon, "Environmental Scarcity and Violent Conflict: The Case of South Africa," *Journal of Peace Research*, special issue on environmental conflict, Vol. 35, No. 3 (May 1998), pp. 279–298; and Günther Baechler, *Violence through Environmental Discrimination: Causes, Rwanda Arena, and Conflict Model* (Dordrecht: Kluwer, 1999).

19. Kurt M. Campbell, Jay Gulledge, J.R. McNeill, John Podesta, Peter Ogden, Leon Fuerth, R. James Woolsey, Alexander T.J. Lennon, Julianne Smith, Richard Weitz, and Derek Mix, "The Age of Consequences: The Foreign Policy and National Security Consequences of Climate Change" (Washington, D.C.: CSIS/CNAS, 2007), http://www.csis.org/media/csis/pubs/071105_ageofconsequences.pdf; CNA Corporation, "National Security and the Threat of Climate Change" (Washington, D.C.: CNA Corporation, 2007); Thomas Fingar, "National Intelligence Assessment on the National Security Implications of Global Climate Change to 2030," statement for the record before the Permanent Select Committee on Intelligence and the Select Committee on Energy Independence and Global Warming, House of Representatives, June 25, 2008, http://www.fas.org/irp/congress/2008_hr/062508fingar.pdf; Paul Herman and Gregory F. Treverton, "The Political Consequences of Climate Change," *Survival*, Vol. 51, No. 2 (April–May 2009), pp. 137–148; Javier Solana, "Climate Change and International Security," paper from the High Representative and the European Commission to the European Council, Council of the European Union, March 14, 2008, http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/reports/99387.pdf; John Podesta and Peter Ogden, "The Security Implications of Climate Change," *Washington Quarterly*, Vol. 31, No. 1 (Winter 2008), pp. 115–138; UN Security Council, "Security Council Holds First-Ever Debate on Impact of Climate Change on Peace, Security, Hearing over 50 Speakers" (New York: UN, 2007), http://www.un.org/News/Press/docs/2007/sc9000.doc.htm; and WBGU, "Climate Change as a Security Risk: Summary for Policymakers," Flagship Report (Berlin: German Advisory Council on Climate Change, 2007), http://www.wbgu.de/wbgu_jg2007_kurz_engl.html.

20. See the special January 2012 issue of *Journal of Peace Research* on climate and security. See also Halvard Buhaug, "Climate Not to Blame for Africa's Civil Wars," *Proceedings of the National Academy of Sciences*, Vol. 107, No. 38 (September 2010), pp. 16477–16482; Solomon M. Hsiang, Kyle C. Meng, and Mark A. Cane, "Civil Conflicts Are Associated with the Global Climate," *Nature*, August 2011, pp. 438–441; Ole Magnus Theisen, Helge Holtermann, and Halvard Buhaug, "Climate Wars? Assessing the Claim That Drought Breeds Conflict," *International Security*, Vol. 36, No. 3 (Winter 2011/12), pp. 79–106; John O'Loughlin, Frank D.W. Witmer, Andrew M. Linke, Arlene Laing, Andrew Gettelman, and Jimy Dudhiab, "Climate Variability and Conflict Risk in East Africa, 1990–2009," *Proceedings of the National Academy of Sciences*, Vol. 109, No. 45 (October 2012), pp. 18344–18349, http://www.pnas.org/content/early/2012/10/17/1205130109; Halvard Buhaug, Nils Petter Gleditsch, and Ole Magnus Theisen, "Implications of Climate Change for Armed Conflict" (Washington, D.C.: Social Development Department, World Bank, 2008), http://siteresources.worldbank.org/INTRANETSOCIALDEVELOPMENT/Resources/SDCC WorkingPaper_Conflict.pdf; Marshall B. Burke, Edward Miguel, Shanker Satyanath, John A.

have been mixed and somewhat disappointing, in part because of the lack of adequate data.[21] 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.[22] Climate change does, however, constitute a security concern beyond its potential contribution to violent conflict, as it is expected to increase the number and severity of extreme weather events.[23] Given that militaries are frequently deployed to provide humanitarian relief in the aftermath of extreme weather events, such crises constitute important security concerns for governments, if only because the diversion of military resources represents an opportunity cost and could keep such resources from being deployed for other purposes.[24]

Moreover, in poor, fragile states, such as many of those in Africa, climate shocks and swift-onset meteorological shocks potentially constitute more severe threats to domestic security by compromising a state's monopoly of force within its borders.[25] In the absence of effective delivery of relief supplies, the

Dykema, and David B. Lobell, "Warming Increases the Risk of Civil War in Africa," *Proceedings of the National Academy of Sciences*, Vol. 106, No. 49 (November 2009), pp. 20670–20674; Cullen S. Hendrix and Sarah M. Glaser, "Trends and Triggers: Climate Change and Civil Conflict in Sub-Saharan Africa," *Political Geography*, Vol. 26, No. 6 (August 2007), pp. 695–715; and Marc A. Levy, Catherine Thorkelson, Charles Vörösmarty, Ellen Douglas, and Macartan Humphreys, "Freshwater Availability Anomalies and Outbreak of Internal War: Results from a Global Spatial Time Series Analysis," paper presented at the "Human Security and Climate Change" workshop, Asker, Norway, June 21–23, 2005, http://www.ciesin.columbia.edu/pdf/waterconflict.pdf.

21. Buhaug, Gleditsch, and Theisen, "Implications of Climate Change for Armed Conflict"; Joshua Busby, "Feeding Insecurity? Poverty, Weak States, and Climate Change," in Susan Rice, Corinne Graff, and Carlos Pascual, eds., *Confronting Poverty: Weak States and U.S. National Security* (Washington, D.C.: Brookings Institution Press, 2009), pp. 125–166; and Joshua Busby, "The Climate Security Connection: What It Means for the Poor," in Lael Brainard, Abigail Jones, and Nigel Purvis, eds., *Climate Change and Global Poverty: A Billion Lives in the Balance?* (Washington, D.C.: Brookings Institution Press, 2009), pp. 155–180.

22. Roland Paris, "Human Security: Paradigm Shift or Hot Air?" *International Security*, Vol. 26, No. 2 (Fall 2001), p. 87; and Roland Paris, "Still an Inscrutable Concept," *Security Dialogue*, Vol. 35, No. 3 (September 2004), pp. 370–372.

23. IPCC, *Climate Change 2007: Impacts, Adaptation, and Vulnerability* (Cambridge: Cambridge University Press, 2007), http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm.

24. Joshua Busby, "Climate Change and National Security: An Agenda for Action" (New York: Council on Foreign Relations, 2007), www.cfr.org/publication/14862; and Joshua Busby, "Who Cares about the Weather? Climate Change and U.S. National Security," *Security Studies*, Vol. 17, No. 3 (July 2008), pp. 468–504.

25. Dawn Brancati, "Political Aftershocks: The Impact of Earthquakes on Intrastate Conflict," *Journal of Conflict Resolution*, Vol. 51, No. 5 (October 2007), pp. 715–743; Philip Nel and Marjolein Righarts, "Natural Disasters and the Risk of Violent Civil Conflict," *International Studies Quarterly*, Vol. 52, No. 1 (March 2008), pp. 159–185. For contrasting views on the connections between disasters and violence, see Rune T. Slettebak, "Don't Blame the Weather! Climate-Related Natural Disasters and Civil Conflict," *Journal of Peace Research*, Vol. 49, No. 1 (January 2012), pp. 163–176; Drago Bergholt and Päivi Lujala, "Climate-Related Natural Disasters, Economic Growth, and

destruction of infrastructure and interruption of services could potentially contribute to such desperation that the populace will steal or riot to secure necessities.[26] 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.[27]

We emphasize the potential security consequences of climate change, including but not limited to conflict, encompassing situations where weather-related phenomena put large numbers of people at risk of mass death.[28] The security focus makes our work different from that of the United Nations International Strategy for Disaster Reduction (UNISDR), which focuses on mortality and economic losses from disasters.[29] We are especially interested in the impact of climate-related hazards where physical exposure, compounded by other sources of vulnerability, will likely endanger the lives of such large numbers of people that local emergency rescue personnel cannot cope. In those instances, emergency relief will often require the mobilization of domestic and foreign militaries. In some cases, such crises will make internal conflict more likely and will contribute to other potential security outcomes of interest, including internal and international migration. This discussion raises the question of how to identify which areas are potentially vulnerable to these security consequences, in turn leading us to examine the concept of vulnerability and its relation to climate change.

Understanding Vulnerability and Climate Change

What makes a place potentially vulnerable to the security consequences of climate change? Answering this question requires an understanding of the

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Armed Civil Conflict," *Journal of Peace Research*, Vol. 49, No. 1 (January 2012), pp. 147–162; and Rustad et al., "All Conflict Is Local."

26. Cullen S. Hendrix and Idean Salehyan, "Climate Change, Rainfall, and Social Conflict in Africa," *Journal of Peace Research*, Vol. 49, No. 1 (January 2012), pp. 35–50.

27. Alejandro Quiroz Flores and Alastair Smith, "Surviving Disasters" (New York: Wilf Family Department of Politics, New York University, 2010), http://politics.as.nyu.edu/docs/IO/14714/Surviving_Disasters.pdf; and Alastair Smith and Alejandro Quiroz Flores, "Disaster Politics," *Foreign Affairs*, July 15, 2010, http://www.foreignaffairs.com/articles/66494/alastair-smith-and-alejandro-quiroz-flores/disaster-politics.

28. As Rustad et al. argue, including both disaster relief capacity and conflict risk is warranted: "Those factors associated with a state's ability to effectively conduct relief operations as well as mitigating the risk of natural disaster are the same factors found to be associated with the risk of armed conflict." Rustad et al., "All Conflict Is Local," p. 20.

29. United Nations International Strategy for Disaster Reduction (UNISDR), *Risk and Poverty in a Changing Climate: Invest Today for a Safer Tomorrow*, Global Assessment Report on Disaster Risk Reduction (Geneva: UNISDR, 2009), http://www.preventionweb.net/english/hyogo/gar/report/index.php?id=9413.

broader field of vulnerability studies. Conceptual fragmentation characterizes the literature on vulnerability. Different disciplines and professions understand the concept differently.[30] The Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) defines 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."[31]

Vulnerability is also often identified as susceptibility to losses of lives and livelihoods. Ben Wisner, for example, suggests that across the diverse meanings of vulnerability is the notion of "potential for disruption or harm."[32] Omar 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."[33] 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, are able to respond quickly to emergencies and to 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 × hazard.[34] 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. Nick Brooks, Neil Adger, and Mick Kelly seek to operationalize risk with respect to disaster mortality, where the probability that a country will be exposed to a climate-related or

30. For a variety of definitions, see David Alexander, "Theoretical Notes on Vulnerability to Disaster," *Disaster Planning and Emergency Management*, blog, January 31, 2009, http://emergency-planning.blogspot.com; Omar D. Cardona, "The Need for Rethinking the Concepts of Vulnerability and Risk from a Holistic Perspective: A Necessary Review and Criticism for Effective Risk Management," in Greg Bankoff, Georg Frerks, and Dorothea Hilhorst, eds., *Mapping Vulnerability: Disasters, Development, and People* (London: Earthscan, 2004), pp. 37–51; Hans-Martin Füssel and Richard J.T. Klein, "Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking," *Climatic Change*, April 2006, pp. 301–329; Robert McLeman and Barry Smit, "Vulnerability to Climate Change Hazards and Risks: Crop and Flood Insurance," *Canadian Geographer*, Vol. 50, No. 2 (Summer 2006), pp. 217–226; Raleigh, Jordan, and Salehyan, "Assessing the Impact of Climate Change on Migration and Conflict"; Juergen Weichselgartner, "Disaster Mitigation: The Concept of Vulnerability Revisited," *Disaster Prevention and Management*, Vol. 10, No. 2 (2001), pp. 85–94; and Ben Wisner, "Assessment of Capability and Vulnerability," in Bankoff, Frerks, and Hilhorst, *Mapping Vulnerability*, pp. 183–193.

31. See IPCC, *Climate Change 2007: Synthesis Report: An Assessment of the Intergovernmental Panel on Climate Change* (Cambridge: Cambridge University Press, 2007), p. 21, box 2.

32. Wisner, "Assessment of Capability and Vulnerability," p. 184.

33. Cardona, "The Need for Rethinking the Concepts of Vulnerability and Risk from a Holistic Perspective," p. 37.

34. Alexander, "Theoretical Notes on Vulnerability to Disaster"; and Burg, "Measuring Populations' Vulnerabilities for Famine and Food Security Interventions."

meteorological event and its vulnerability to this event reflect the event's likely consequence or importance.[35] In this equation, environmental and physical factors contribute to risk, whereas vulnerability is narrowly defined in socioeconomic and political terms. A focus on vulnerability as a purely social understanding could be misleading, however. 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."[36] Another tendency might be to examine vulnerability purely in terms of physical exposure. Clionadh Raleigh, Lisa Jordan, and Idean Salehyan suggest that—despite the inclusion of measures of a society's adaptive capacity in its definition of vulnerability—the IPCC definition emphasizes mainly physical risks rather than the social and economic sources of vulnerability.[37]

Some authors define risk and vulnerability interchangeably, whereas 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 of vulnerability (physical, demographic, social, and political sources) that expose large numbers of people to disruptive losses such that their physical security cannot be assured without external relief or the affected populations respond by engaging in behavior such as theft, looting, riots, strikes, and demonstrations that potentially escalate into more violence.

Other studies have tried to assess the relative vulnerability of different countries to climate change, including work by Raleigh, Jordan, and Salehyan; research by Marc Levy et al.; papers by Brooks, Adger, and Kelly; work by Antoinette Brenkert and Elizabeth Malone; and, finally, research by David Wheeler. These studies have made important contributions, but they also have their limitations. Here, we discuss all five of these approaches to vulnerability.

In their effort to capture vulnerability to disasters, Raleigh, Jordan, and Salehyan incorporate just three dimensions: (1) gross domestic product (GDP) per capita; (2) population growth by 2050; and (3) historic disaster frequency.[38] 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, including windstorms, droughts, and floods. A spare metric of vulnerability provides

35. Nick Brooks, W. Neil Adger, and P. Mick Kelly, "The Determinants of Vulnerability and Adaptive Capacity at the National Level and the Implications for Adaptation," *Global Environmental Change*, Vol. 15, No. 2 (July 2005), pp. 151–163.
36. Cardona, "The Need for Rethinking the Concepts of Vulnerability and Risk from a Holistic Perspective," p. 38.
37. Raleigh, Jordan, and Salehyan, "Assessing the Impact of Climate Change on Migration and Conflict."
38. Ibid.

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. One of their input indicators, however, is the EM-DAT International Disaster database compiled by the Université Catholique de Louvain in Belgium. By using the EM-DAT data on disasters, Raleigh, Jordan, and Salehyan potentially conflate physical exposure with other dimensions of vulnerability. The EM-DAT database counts an event as a disaster only if the consequences meet one of the following conditions: ten or more people killed; a hundred or more people reported affected; a declaration of a state of emergency; or a call for international assistance.[39] 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. To avoid the problem identified above, we use indicators of physical exposure to climate-related hazards that are measured independently of their ultimate impact on people (see online appendix table 10 for Raleigh, Jordan, and Salehyan's list of most vulnerable countries).[40]

Emphasizing the potential security consequences of climate change, Levy et al. include several governance and political measures of vulnerability. They examine 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.[41] They compare 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.[42] Levy et al.'s

39. The EM-DAT dataset is in part a reflection of reporting, so the patterns may not fully reflect all the disasters or they may be biased toward countries that have more media attention. Moreover, the data on fatalities, people affected, and homelessness may be inaccurate.
40. See CRED, "EM-DAT."
41. Marc A. Levy, Bridget Anderson, Melanie Brickman, Chris Cromer, Brian Falk, Balazs Fekete, Pamela Green, Malanding Jaiteh, Richard Lammers, Valentina Mara, Kytt MacManus, Steve Metzler, Maria Muñiz, Thomas Parris, Randy Pullen, Catherine Thorkelson, Charles Vorosmarty, Wil Wollheim, Xiaoshi Xing, and Greg Yetman, "Assessment of Select Climate Change Impacts on U.S. National Security," Working Paper (Palisades, N.Y.: CIESIN, 2008), http://www.ciesin.columbia.edu/documents/Climate_Security_CIESIN_July_2008_v1_0.ed.pdf.
42. 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

paper has several virtues. First, it incorporates models of future climate vulnerability. Historic patterns of exposure to climate hazards may not reflect future climate vulnerability, given that future climate change may not take place in the regions where previous extreme weather events took place. Second, it includes several indicators of political risk and instability, which makes the authors' work more relevant to the emergent climate security literature. Third, their research includes attributes of government effectiveness thought important in disaster response.

That said, Levy et al.'s approach has some potential flaws. First, there is no single risk or vulnerability rating scheme. Rather, each indicator of physical exposure is overlaid on one or at most two indicators of instability in a series of maps, leaving readers to draw their own conclusions about which countries consistently show up on the most vulnerable lists. Second, their approach also omits 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, particularly for Africa, is highly uncertain, given data limitations and challenges of "downscaling" global climate models to produce valid regional projections. Therefore, an approach that compares historical exposure to climate-related hazards with future climate projections would be beneficial (see online tables appendix that summarizes several of the Levy et al. models in a single chart).

Brooks, Adger, and Kelly synthesize the diverse sources of country vulnerability to generate a portrait of global vulnerability. Using generic indicators as proxies for common processes potentially affecting all countries, they focus on populations' vulnerability to mortality from natural disasters. After examining forty-six indicators identified in the literature as potentially relevant to vulnerability, they select eleven to pursue for strategic assessment and construction of a global ranking of national-level vulnerability.[43] These eleven indicators are proxies for variables from three broad areas: education, health, and governance. The education basket included three indicators: literacy rate for fifteen to twenty-four-year-olds, literacy rate of those older than fifteen, and the overall literacy

2005. Countries with thirty or more events were considered "extremely high" in terms of instability. Countries whose neighbors had thirty or more events were considered to be in "very dangerous" neighborhoods. Levy et al., "Assessment of Select Climate Change Impacts on U.S. National Security."

43. Brooks, Adger, and Kelly, "The Determinants of Vulnerability and Adaptive Capacity at the National Level and the Implications for Adaptation." For a more detailed discussion, see W. Neil Adger, Nick Brooks, Graham Bentham, Maureen Agnew, and Siri Eriksen, "New Indicators of Vulnerability and Adaptive Capacity," Technical Report, No. 7 (Norwich, U.K.: Tyndall Center, University of East Anglia, 2004), http://www.tyndall.ac.uk/sites/default/files/it1_11.pdf.

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 [i.e., the willingness of a government to listen to its people]) and two from Freedom House indicators (political rights and civil liberties).

Brooks, Adger, and Kelly selected these eleven indicators after subjecting all forty-six indicators to Monte Carlo simulations to identify which were statistically correlated with an increase in mortality from climate-related disasters in small island nation-states.[44] They then derived rankings 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 fifteen to twenty-four-year-olds; (6) political rights; (7) literacy of those older than fifteen; (8) civil liberties; (9) literacy ratio; (10) average calorie intake; and (11) maternal mortality. Given the authors' rigorous methodology, we draw heavily on these indicators in our subsequent composite index. The selected indicators include some that are highly correlated, however; 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 0.95 within African countries. Similarly, the Freedom House indicators are highly correlated with the World Bank indicators at 0.90 or greater. The construction of the index could also lead to biases and conclusions that could 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, Adger, and Kelly underplay the significance of geographic and physical components of vulnerability. As a consequence, countries known to be highly geographically vulnerable to climate change appear

44. In this regard, the research by Brooks, Adger, and Kelly is similar to that of our research partners Timmons Roberts and Bradley Parks. Whereas Brooks and his colleagues 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 colonial heritage and the ways in which developing countries have become inserted in the global economy as exporters of primary commodities. See Brooks, Adger, and Kelly, "The Determinants of Vulnerability and Adaptive Capacity at the National Level and the Implications for Adaptation"; and J. Timmons Roberts and Bradley C. Parks, *A Climate of Injustice: Global Inequality, North-South Politics, and Climate Policy* (Cambridge, Mass.: MIT Press, 2007).

unworthy of concern. For example, across the thirteen separate weighting schemes, Bangladesh appeared in the upper vulnerability quintile of only one of them (see online tables appendix for their most vulnerable list).

Brenkert and Malone, part of a larger Pacific Northwest National Laboratory research team, have also developed indices of climate vulnerability since 2001 with the use of their Vulnerability-Resilience Indicator Model (VRIM). They provide mostly national rankings, but they have also made a preliminary effort to rank Indian states. The VRIM includes seventeen indicators. Brenkert and Malone suggest that vulnerability is a function of three factors: exposure, sensitivity, and adaptive capacity, though only sensitivity and adaptive capacity are represented in the indicators.[45] They then group indicators into sectors, and weight each indicator equally. Within the sensitivity basket, they include the following sectors: food security, water resources, settlement and infrastructure, human health, and ecosystem. Under the adaptive capacity basket, they include environmental capacity, economic capacity, and human civic resources.[46] Governance indicators are not included, however—a notable exclusion given the importance of these indicators for India and the authors' own comments about the role of India's democracy. One of the inspirations for contemporary vulnerability studies is 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.[47] In VRIM, moreover, exposure largely drops out; indicators of exposure near coasts are not accounted for except through the population indicator (see the online tables appendix for their most vulnerable list).[48]

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45. 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. Antoinette L. Brenkert and Elizabeth L. Malone, "Modeling Vulnerability and Resilience to Climate Change: A Case Study of India and Indian States," *Climatic Change*, Vol. 72, Nos. 1–2 (September 2005), pp. 63–64.

46. Ibid.; Richard H. Moss, Antoinette Brenkert, and Elizabeth Malone, "Vulnerability to Climate Change: A Quantitative Approach" (College Park, Md.: Pacific Northwest National Laboratory, University of Maryland, 2001), http://www.globalchange.umd.edu/publications/118/; Gary Yohe, Elizabeth Malone, Antoinette Brenkert, Michael Schlesinger, Henk Meij, Xiaoshi Xing, and Daniel Lee, "A Synthetic Assessment of the Global Distribution of Vulnerability to Climate Change from the IPCC Perspective That Reflects Exposure and Adaptive Capacity" (Palisades, N.Y.: CIESIN, 2006), http://www.ciesin.columbia.edu/data/climate/sagdreport.pdf; and Gary Yohe, Elizabeth Malone, Antoinette Brenkert, Michael Schlesinger, Henk Meij, and Xiaoshi Xing, "Global Distributions of Vulnerability to Climate Change," *Integrated Assessment Journal*, Vol. 6, No. 3 (2006), pp. 35–44.

47. Amartya Sen, *Poverty and Famines: An Essay on Entitlement and Deprivation* (Oxford: Oxford University Press, 1981).

48. For example, in a 2009 study, the Center for Naval Analyses used the VRIM but added expo-

Another approach to climate vulnerability is work by David Wheeler of the Center for Global Development. In 2011, Wheeler provided climate vulnerability rankings for 233 states.[49] He created a composite index of vulnerability to climate change for these countries with projections for the period 2008–15. Wheeler also developed an econometric model to assess the likelihood that a country will experience a climate disaster. Using climate-related disasters from the EM-DAT database as his dependent variable, Wheeler seeks to explain historic vulnerability to disasters using concentrations of greenhouse gases, population, income per capita, voice and accountability, and quality of regulation. He finds that greenhouse gases, population, and voice and accountability are correlated with a greater likelihood of disasters (the latter a function of media openness that allows reporting), whereas income per capita and quality of regulation are negatively correlated with disasters. Wheeler develops a multiplicative index of climate vulnerability, a function of both exposure to physical risks and resilience. He captures the risk of climate change based on exposure to climate-related hazards, sea-level rise, and changes in agricultural yields. His measures of resilience include income per capita and regulatory quality. He finds that African countries comprised sixteen of the world's most vulnerable states (see online tables appendix). Vulnerabilities are, however, still identified at the national, rather than subnational, level.

From these diverse approaches, we derived a number of lessons about how to model climate security vulnerability at the subnational level. Vulnerability to extreme weather events is only partially a function of exposure to environmental and geographic features.[50] Whether or not a climate-related hazard becomes a "disaster" is ultimately contingent upon a host of other factors, including community resilience and government effectiveness. In addition to living in areas prone to flooding, drought, or other extreme weather events, communities are often made more vulnerable because their members are in ill health and undereducated. They lack adequate public infrastructure—such as roads, piped water, sanitation, and electricity—or access to health care, education, and other basic services. These risks may be compounded by a lack of political representation, poor governance, or a history of violence. As this discussion implies, "natural" disasters are something of a misnomer.[51] Draw-

sure and governance data from other sources. Marcus D. King and Ralph H. Espach, *Global Climate Change and State Stability* (Washington, D.C.: CNA Corporation, 2009).
49. David Wheeler, "Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance," Working Paper, No. 240 (Washington, D.C.: Center for Global Development, 2011), http://www.cgdev.org/content/publications/detail/1424759/.
50. Basher and Briceño, "Climate and Disaster Risk Reduction in Africa," p. 276.
51. Ibid.

ing on these insights, we aimed to generate a single map of subnational climate security vulnerability, a snapshot of the places we think are likely to be chronic places of concern.

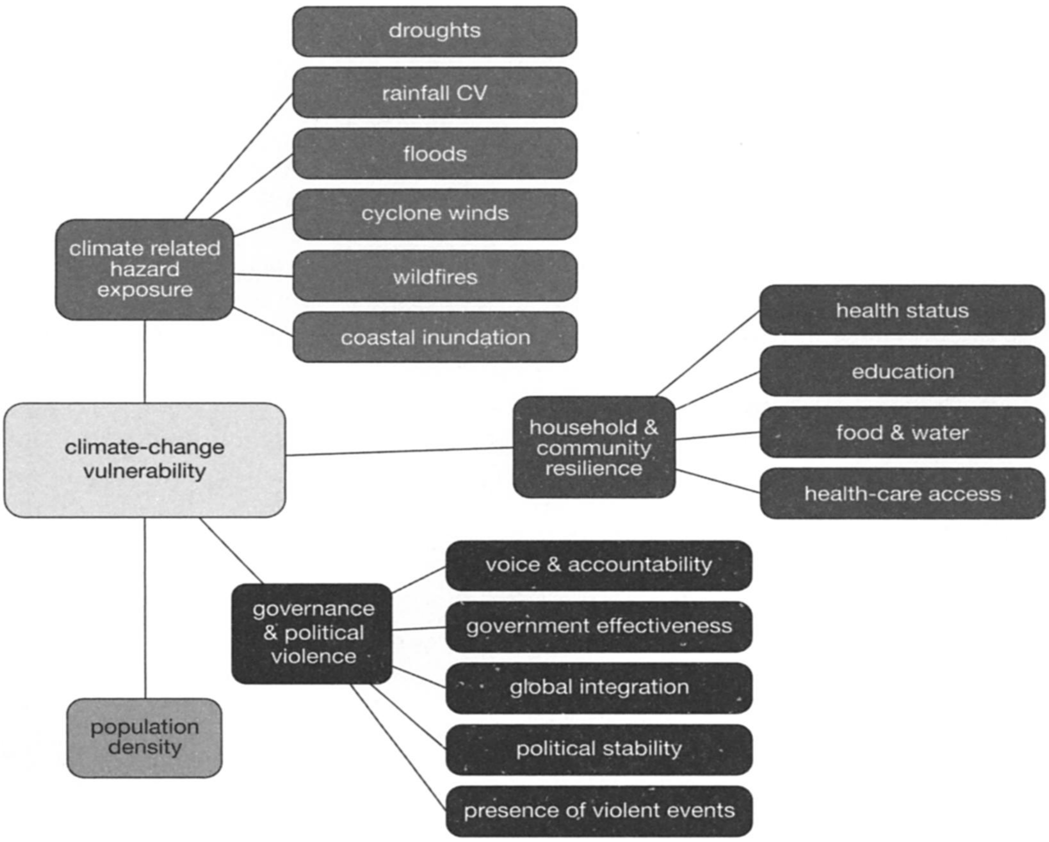
Methodology of Climate Security Vulnerability Mapping

Given the limitations of the existing vulnerability literature, our approach includes an amalgam of indicators of physical exposure and social and political sources of vulnerability. We grouped these sources into four main processes, or baskets, to represent different aspects of climate security vulnerability: (1) physical exposure to climate-related hazards; (2) population density; (3) household and community resilience; and (4) governance and political violence.[52] We selected these baskets and the indicators within them based on deductive theory about the likely determinants of climate security risks; the state of the empirical literature on climate, conflict, and disaster vulnerability; and the realities of continent-wide data sources for Africa. This section provides a thumbnail sketch of our vulnerability mapping methodology. Readers interested in more detail should consult the online methodological appendix.

Following conventions among many studies that employ indices such as the Human Development Index, the VRIM, and the Commitment to Development Index, all four baskets have equal weight in the final vulnerability analysis (we later relax this assumption in sensitivity analyses).[53] Despite some scholars' objections to using composite indices, their principal value is the ease with which a summary statistic can help to synthesize complex, multidimensional data.[54] Three of the four baskets include several indicators to reflect that dimension; the exception is population density, which is composed of a single indicator (see figure 1 for a representation of the four baskets and indicators).

52. Cardona expresses a similar framework identifying the origins of vulnerability in physical fragility or exposure, socioeconomic fragility, and lack of resilience. See Cardona, "The Need for Rethinking the Concepts of Vulnerability and Risk from a Holistic Perspective," p. 49.
53. The Human Development Index adopted a more complex methodology in November 2010. For a discussion of the virtues of equal weights in composite indices, see Lee Stapleton and Guy D. Garrod, "Keeping Things Simple: Why the Human Development Index Should Not Diverge from Its Equal Weights Assumption," *Social Indicators Research*, Vol. 84, No. 2 (November 2007), pp. 179–188; and Lee Stapleton and Guy D. Garrod, "The Commitment to Development Index: An Information Theory Approach," *Ecological Economics*, Vol. 66, Nos. 2–3 (June 2008), pp. 461–467. For a discussion of problems with equal weight-based indices, see Shyamal Chowdhury and Lyn Squire, "Setting Weights for Aggregate Indices: An Application to the Commitment to Development Index and Human Development Index," *Journal of Development Studies*, Vol. 42, No. 5 (August 2006), pp. 761–771.
54. For a discussion of the pros and cons of composite indicators, see Organization for Economic Cooperation and Development (OECD), *Handbook on Constructing Composite Indicators: Methodology and User Guide* (Paris: OECD, 2005), http://www.oecd.org/dataoecd/37/42/42495745.pdf.

Figure 1. Diagram of Climate Security Vulnerability Model



This section outlines the rationale for the baskets and the indicators that comprise them. The online methodological appendix provides a more detailed discussion of each component of the baskets.

PHYSICAL EXPOSURE TO CLIMATE-RELATED HAZARDS

Geographic location makes some countries more susceptible to climate change impacts than others. Within countries, some areas, such as the coasts, are more vulnerable to certain kinds of climate-related hazards than other areas. Because climate models for Africa show some disagreement about the expected future distribution of climate-related hazards at the local level, our best proxy for future vulnerability is largely based on historic exposure. We use historic data of the frequency and magnitude of climate-related hazards, including cy-

Table 1. Indicators Used to Assess Physical Exposure to Climate-Related Hazards

Hazard Type (weight)	Data Source	Years of Data Used
Cyclone winds (0.16)*	UNEP/GRID-Europe	1975–2007
Floods (0.16)*	UNEP/GRID-Europe	1999–2007
Wildfires (0.16)*	UNEP/GRID-Europe	1997–2008
Aridity (coefficient of variation) (0.16)*	UNEP/GRID-Europe	1951–2004
Droughts (0.16)*	Global Precipitation Climatology Center	1980–2004
Inundation (coastal elevation) (0.16)*	USGS DEM	1996

*Indicates data source with subnational information—fires, floods, and inundation 1 km by 1 km resolution, cyclones 2 km by 2 km resolution, aridity and drought 0.5 degree resolution.

UNEP/GRID-Europe stands for United National Environment Programme/Global Resource Information Database–Europe, and USGS DEM for United States Geological Survey DEM.

clones, fires, floods, and droughts. We use a measure of the coefficient of variation of precipitation to identify chronic water-scarce areas that may experience water stress even if they are not technically experiencing droughts.[55] We also include a measure of low-elevation coastal zones that may be susceptible to future sea-level rise and higher storm surges. All of the indicators in this basket are subnational with high resolution (see table 1 for a list of the indicators used in the physical exposure basket).

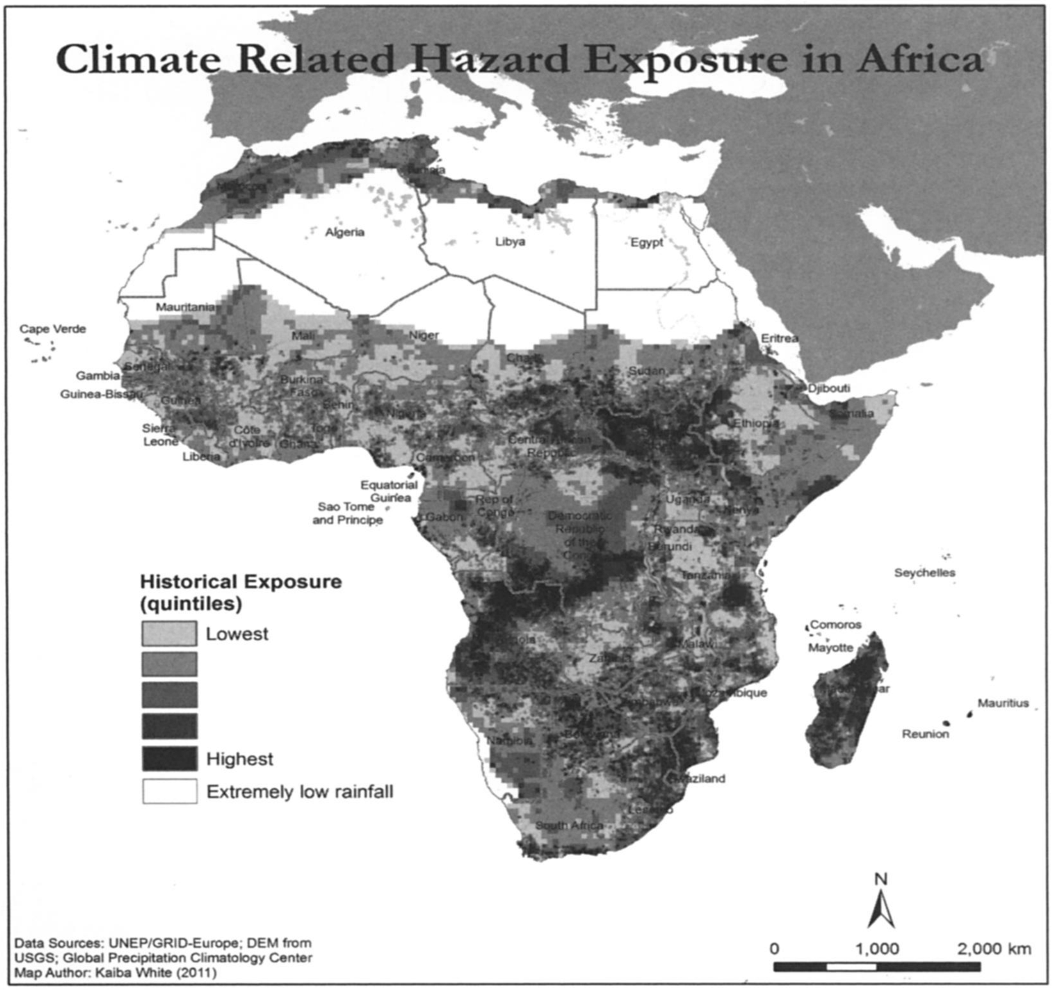
Figure 2 shows relative exposure to historic climate hazards and low-elevation coastal zones within Africa with high physical exposure in pockets along the Mediterranean, western Ethiopia extending across South Sudan, southern DRC, and pockets in Tanzania. Much of southern Africa has pockets of high physical exposure, including parts of Angola, Mozambique, and Madagascar (see figure 2; the online climate hazard appendix has maps of each indicator in this basket).

POPULATION DENSITY

When extreme weather 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 need 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

55. For a more extended discussion of the distinction between droughts, as captured by the Standardized Precipitation Index, and the coefficient of variation, see UNISDR, *Risk and Poverty in a Changing Climate,* p. 45.

Figure 2.



areas. All else being equal, more densely populated areas that are highly exposed to climate-related hazards will put more people at risk of mass death. At the same time, we would expect such areas to command more attention from decisionmakers; therefore, weighting population density would help policymakers to identify areas of high human impact. The population density indicator from LandScan, a map resource displaying population, is subnational with 1-square-kilometer (km) resolution.[56]

56. See note 102 for more information about LandScan. For important discussions of weighing

Figure 3.

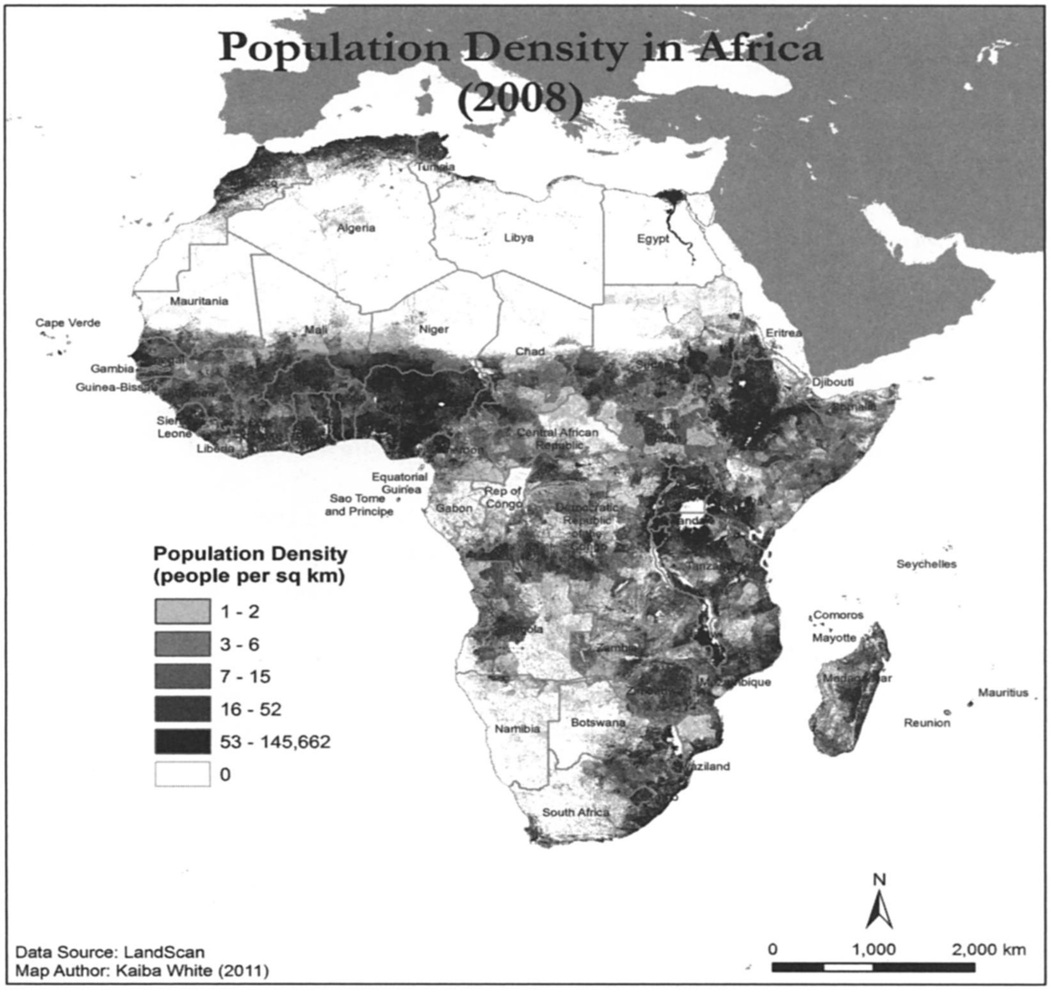


Figure 3 projects the distribution of population density within Africa, which shows dense populations along the Mediterranean coastline, in Egypt along the Nile, throughout western Ethiopia, and in pockets in Sudan around Khartoum. Much of West Africa is densely populated, including but not limited to Nigeria. The Great Lakes region in Central Africa around Uganda,

population, see Pascal Peduzzi, H. Dao, C. Herold, and F. Mouton, "Assessing Global Exposure and Vulnerability towards Natural Hazards: The Disaster Risk Index," *Natural Hazards Earth System Sciences*, Vol. 9, No. 4 (July 2009), p. 1151; and Rustad et al., "All Conflict Is Local," p. 27.

Rwanda, and the eastern part of the DRC also has high population concentrations. Southern Africa is less densely populated by comparison, with slivers of high population in Malawi, along the eastern seaboard, and in pockets around major cities such as Johannesburg (see figure 3).

HOUSEHOLD AND COMMUNITY RESILIENCE

Whether people experience severe negative consequences of climate hazards depends on factors other than physical exposure. The first line of defense for many people will be resources available at the household and community levels to protect themselves from physical hazards and to respond in the event of climate-related emergencies such as floods, droughts, or storms. Communities where many people are sick and have inadequate access to health care and basic amenities are likely to be less resilient than those that are healthier and have greater access to services. People with less education may have less information or fewer entrepreneurial skills to avoid climate hazards or minimize their effects.

Although many national-level statistical studies of vulnerability incorporate per capita GDP as an indicator, doing so does not capture income inequality between regions or households, and subnational data on income are not available continent-wide for income. As discussed in the methodological appendix, a number of indicators of household resilience—which are strongly correlated with income—are available at the subnational level. Therefore, this basket, inspired largely by the work of Brooks, Adger, and Kelly, has eight indicators grouped into four categories: education, health, daily necessities, and access to services. Indicators are drawn from diverse sources including the World Development Indicators, the United States Agency for International Development (USAID), the United Nations Children's Fund (UNICEF), and the Center for International Earth Science Information Network (CIESIN). Education indicators include school enrollment and literacy.[57] Health indicators include infant mortality and life expectancy.[58] Our proxy for access to daily necessities includes measures of the percentage of children under age five suffering from malnutrition and the proportion of the population with access to improved water sources. Finally, the access to services category includes

57. Peduzzi et al. also include similar indicators of health and sanitation in their study of disaster mortality. See supplementary material in Peduzzi et al., "Assessing Global Exposure and Vulnerability towards Natural Hazards."
58. Infant mortality was one of the most robust predictors of political instability in the work of the State Failure Task Force and its successor, the Political Instability Task Force. Jack A Goldstone, Robert H. Bates, David L. Epstein, Ted Robert Gurr, Michael B. Lustik, Monty G. Marshall, Jay Ulfelder, and Mark Woodward, "A Global Model for Forecasting Political Instability," *American Journal of Political Science*, Vol. 54, No. 1 (January 2010), pp. 190–208.

health expenditures per capita and access to nurses and midwives. Only three of these indicators, infant mortality, under-five child malnutrition, and access to improved water sources, are subnational with resolution largely at the first-level administrative unit, typically states or provinces (see table 2).[59]

Countries with the most resilience are the island nations of Seychelles and Mauritius, followed closely by South Africa and the North African countries of Tunisia, Libya, and parts of Egypt. Countries with the least household and community resilience (i.e., the highest vulnerability) are the perennially worst performers in Africa: parts of Chad, the DRC, Ethiopia, Mozambique, Niger, and Somalia (see figure 4 and the online household resilience appendix for maps of individual indicators in this basket).

GOVERNANCE AND POLITICAL VIOLENCE

Weather emergencies frequently exceed the capacities of local communities' emergency services, requiring national-level mobilization to save people from rising waters or from being trapped under rubble and to provide food, water, and shelter for people left homeless or otherwise affected by extreme weather events. Whether or not individuals experience the worst effects of climate-related 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 it can help them to respond when extreme weather events do occur. Governments that are either so lacking in capacity or so 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 exposure to climate hazards. Where countries have a violent history, this too can undermine the task of providing relief supplies. In 2012, for example, the coup in Mali complicated efforts to extend relief supplies to parts of the country experiencing a food crisis.[60] The previous year, Somalia experienced a devastating famine, exacerbated by the Shabaab militia, which initially denied relief organizations the ability to provide aid.[61]

The expert focus group convened by Brooks, Adger, and Kelly identified governance as the most important factor affecting climate vulnerability. The

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59. In some cases, these are aggregated up to a larger area, and in other cases, data availability allows us to project lower-level administrative units for some of these indicators.
60. Bartley Kives, "The Suffering Sahel," *Winnipeg Free Press*, May 12, 2012, http://www.winnipegfreepress.com/local/the-suffering-sahel-150274655.html.
61. Jeffrey Gettleman, "Somalis Starve as Shabab Militants Bar Escape from Famine," *New York Times*, August 1, 2011, http://www.nytimes.com/2011/08/02/world/africa/02somalia.html.

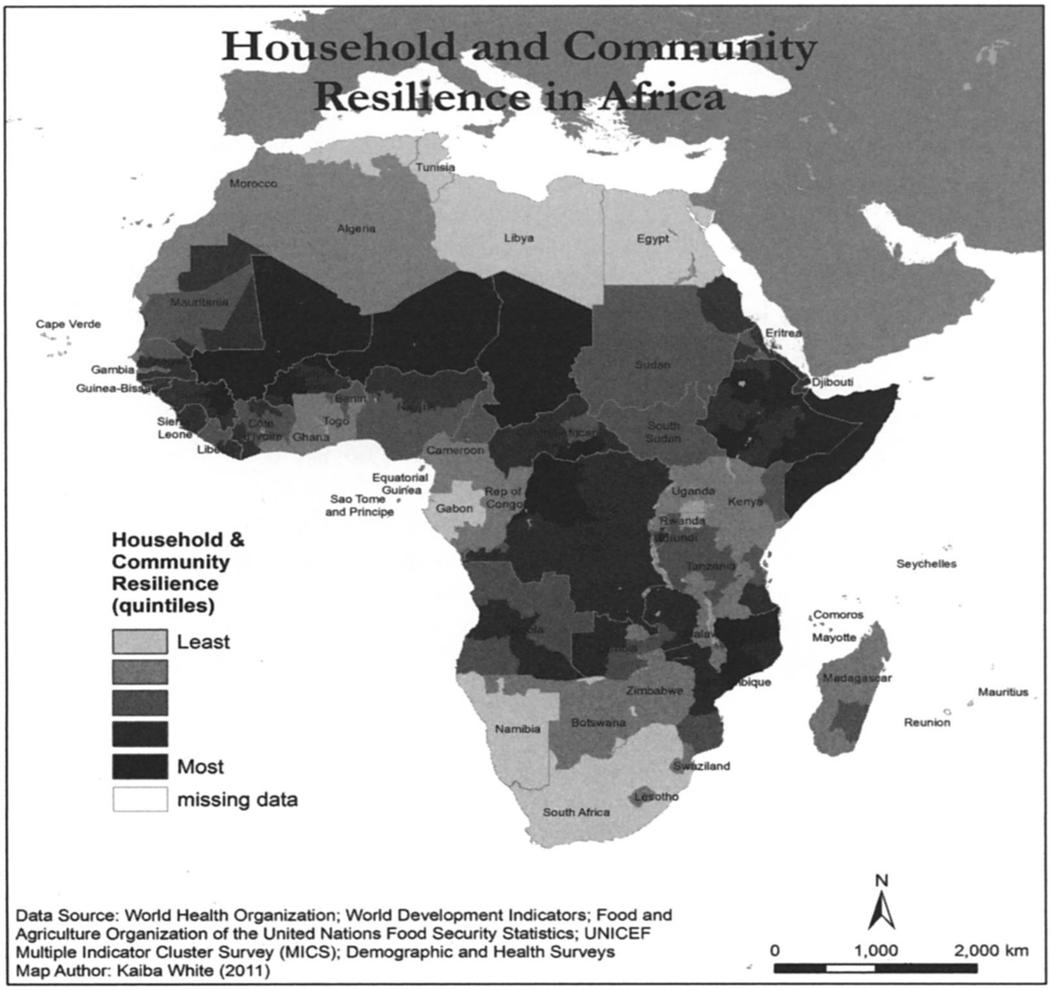
Table 2. Indicators Used to Assess Household and Community Resilience

Variable (weight)	Indicator (weight)	Source	Years of Data Used
Education (0.25)	Literacy rate, adult total (% of people ages 15 and above) (0.125)	WDI	2008; 2007 for Burkina Faso; 2006 for Algeria, Egypt, Mali, and Senegal; 2005 for Niger; no data for Djibouti, Republic of the Congo, or Somalia for
	School enrollment, primary (% gross) (0.125)	WDI	2006–09; 2004 for Gabon
Health (0.25)	Infant mortality rate adjusted to national 2000 UNICEF rate (0.125)*	CIESIN	1991–2003
	Life expectancy at birth (years) both sexes (0.125)	WDI	2008
Daily Necessities (0.25)	Percentage of children underweight (more than two standard deviations below the mean weight-for-age score of the NCHS/CDC/WHO international reference population) (0.125)*	CIESIN	1991–2003
	Population with sustainable access to improved drinking water sources (% total) (0.125)*	USAID Demographic & Health Surveys; UNICEF MICS; WDI	DHS 2000–08; MICS 2005–06; WDI 2008 for Algeria, Botswana, Cape Verde, Comoros, Eritrea, Mauritius, and Tunisia; WDI 2005 for Equatorial Guinea; WDI 2000 for Libya
Access to Healthcare (0.25)	Health expenditure per capita (current U.S.$) (0.125)	WDI	2007; 2005 for Zimbabwe; no data for Somalia
	Nursing and midwifery personnel density (per 10,000 population) (0.125)	WDI	2004–08; 2003 for Lesotho; 2002 for Kenya

*Indicates data source with subnational information, with data assigned to the first level administrative unit in most cases.

UNICEF stands for United Nations Children's Fund; NCHS for National Center for Health Statistics; CDC for Centers for Disease Control; WHO for World Health Organization; CIESIN for Center for International Earth Science Information; USAID for United States Agency for International Development; DHS for Democratic and Health Surveys; MICS for Multiple Indicator Cluster Survey; and WDI for World Development Indicators.

Figure 4.



group employed measures of governance from both the World Bank and Freedom House. Because these measures are highly correlated, we selected only the indicators they employed from the World Bank: voice and accountability and government effectiveness. Voice and accountability reflects the openness of regimes to the needs of their people. In the event of a climate-related emergency, we would expect regimes that are more willing to hear their citizens' pleas for assistance to be more willing to respond. Government effectiveness captures the ability of a government to implement policy. Although this particular measure does not explicitly measure disaster relief capabilities, we do expect that governments with greater effectiveness will prove better able to deliver services in emergencies.

We also recognized, however, that other governance-related attributes may affect whether or not populations facing climate-related hazards receive assistance in times of great need. First, politically unstable regimes likely confront difficult challenges in delivering services because they face significant risks of recurring violence.[62] As discussed more fully in the online methodological appendix, we provide two indicators of political stability based on Polity IV data (though we split the index weight between them so that political instability is weighted the same as the other indicators in the basket). We see regimes in transition, both those that are becoming more autocratic and those that are becoming more democratic, as vulnerable. While democratizing regimes are more likely to be sensitive to the needs of their people, they also tend to be conflict prone. Given the challenges of establishing rule of law and democratic institutions, such countries may lack established patterns of service delivery.[63] More broadly, regimes experiencing volatility will likely be less able or less willing to respond to climate-related emergencies.

Second, the degree to which countries can tap into global networks of assistance may also influence the support that people receive in times of need. In extreme circumstances, populations living under autarkic regimes may be largely cut off from external assistance. For example, the U.S. Navy was willing to provide assistance after Cyclone Nargis in 2008, but the Myanmar government denied them entry. Here, we use a measure of the degree of global integration from the KOF Index of Globalization to reflect the extent to which a country is internationally integrated and can call on other countries in times of need.[64]

Third, areas with a history of violence may be unwilling or unable to provide assistance in times of emergency.[65] While state-led violence against civilians in a particular area represents an obvious category of concern, we would also expect areas where there has been substantial violence between militias to potentially interrupt or make assistance difficult, even for governments will-

62. OECD, *Service Delivery in Fragile Situations: Key Concepts, Findings, and Lessons* (Paris: OECD, 2008), http://www.oecd.org/dataoecd/17/54/40886707.pdf. See also Håvard Hegre and Nicholas Sambanis, "Sensitivity Analysis of Empirical Results on Civil War Onset," *Journal of Conflict Resolution*, Vol. 50, No. 4 (August 2006), pp. 508–535.
63. Michael McFaul, "Are New Democracies War-Prone?" *Journal of Democracy*, Vol. 18, No. 2 (April 2007), pp. 160–167.
64. See KOF, "KOF Index of Globalization," 2009, http://globalization.kof.ethz.ch/.
65. Conflict history is also one of the most robust predictors of future conflict. See Rustad et al., "All Conflict Is Local"; and Goldstone et al., "A Global Model for Forecasting Political Instability."

Table 3. Indicators Used to Assess Governance and Political Violence

Variable	Indicator (weight)	Source	Years of Data Used
Government responsiveness	voice & accountability (0.2)	Worldwide Governance Indicators	2007, 2008, 2009
Government response capacity	government effectiveness (0.2)	Worldwide Governance Indicators	2007, 2008, 2009
Openness to external assistance	globalization index (0.2)	KOF Index of Globalization	2009
Political stability	polity variance (0.1)	Polity IV Project	1999–2008
	Number of stable years (as of 2008) (0.1)	Polity IV Project	1855–2008
Presence of violence	Battles and violence against civilians (0.2)*	Armed Conflict Location and Events Dataset (ACLED)	1997–2009

*Indicates data source with subnational information, with the ACLED events assigned to the lowest administrative unit where available, ranging from the first level to the fourth level.

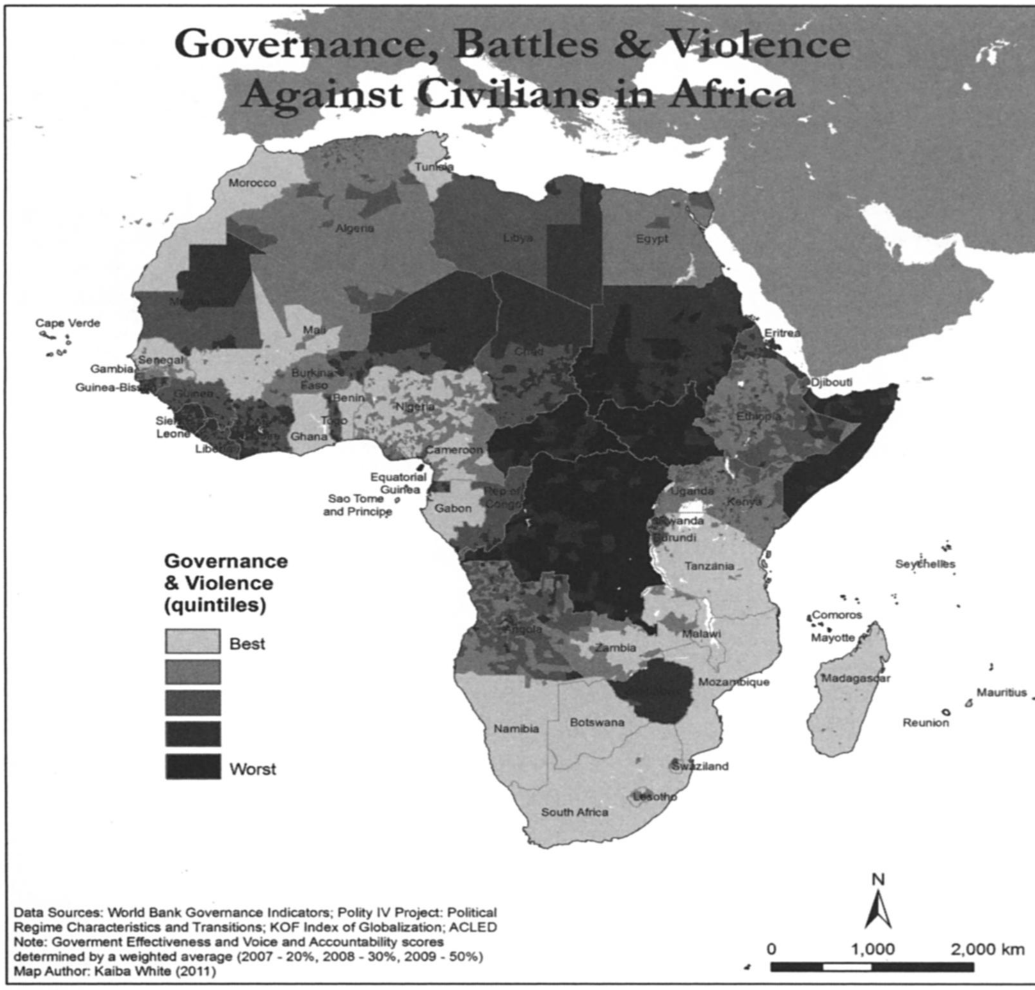
ing to extend service delivery. Again, the Somalia example of 2011 is illustrative. The weak central government and its international partners had difficulty extending relief aid to famine areas because of al-Shabaab opposition.

Of these various governance indicators, the only one that contains subnational data is the Armed Conflict Location and Events Dataset (ACLED). We used localized conflict events and assigned them to the smallest administrative area possible, which ranged from level-one provincial/state data to level-four municipal data (see table 3 for the governance basket data sources).[66]

Figure 5 reveals pockets of high vulnerability, driven by localized atrocities, throughout the Central African Republic, the DRC, Somalia, Sudan, and South Sudan. Parts of West Africa, including Côte d'Ivoire and parts of Nigeria, also suffer from poor governance and political violence (see figure 5; see also the online governance and political violence appendix for maps of individual indicators in this basket).

66. Clionadh Raleigh, Andrew Linke, and Håvard Hegre, "Armed Conflict Location and Events Dataset (ACLED)" (Oslo: International Peace Research Institute, 2009), http://www.acleddata.com/. For this article, ACLED was contracted to include continent-wide Africa coverage. Clionadh Raleigh, Andrew Linke, Håvard Hegre, and Joakim Karlsen , "Introducing ACLED: An Armed Conflict Location and Event Dataset: Special Data Feature," *Journal of Peace Research*, Vol. 47, No. 5 (September 2010), pp. 651–660. Earlier iterations of our work used the Kansas Event Data System (KEDS) dataset on atrocities. ACLED is more comprehensive in its inclusion of civil war events. KEDS, "Political Instability Task Force Worldwide Atrocities Dataset," 2009, http://web.ku.edu/~keds/data.dir/atrocities.html.

Figure 5.

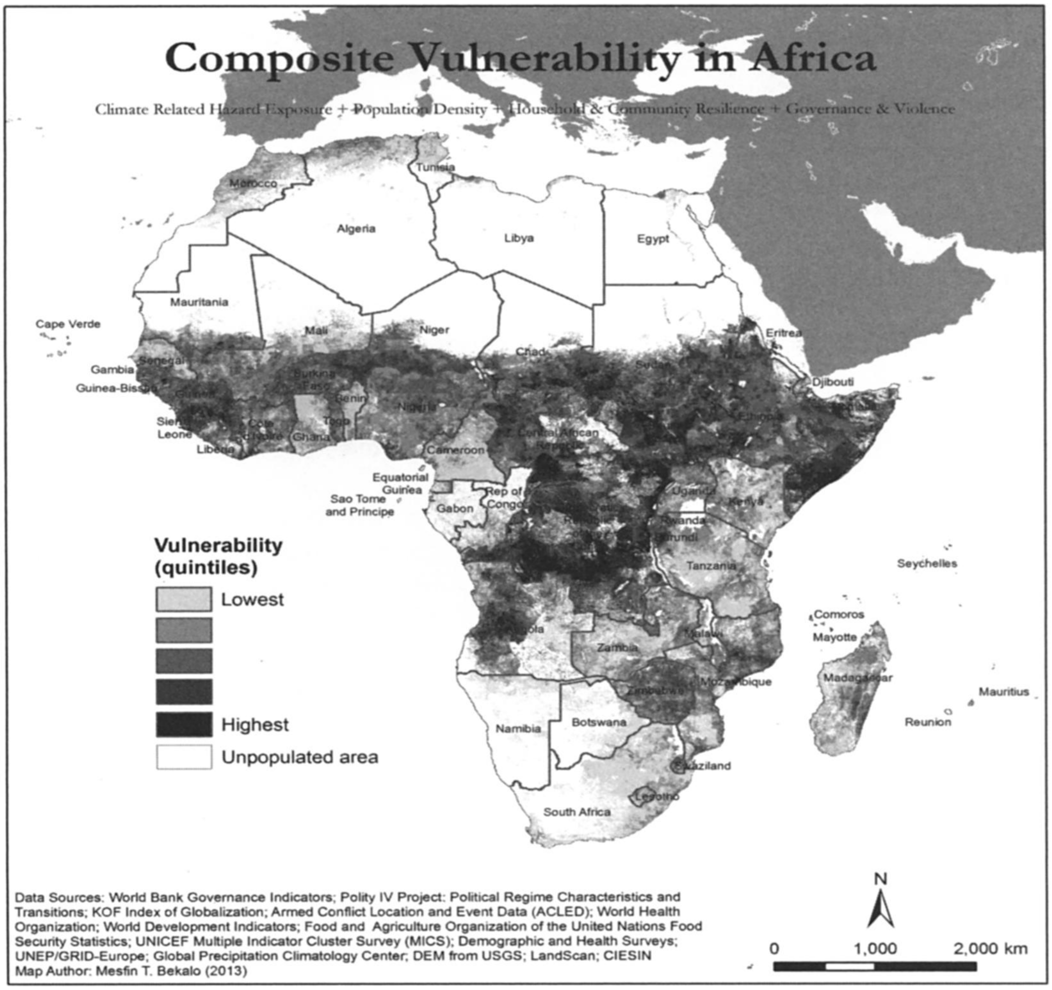


Findings: Hot Spots of Chronic Climate Security Vulnerability

After we combine the four baskets to generate a composite map, we observe a number of interesting patterns (see figure 6). Areas of most acute composite vulnerability include parts of the DRC, Guinea, Sierra Leone, Somalia, and South Sudan.

We can demonstrate the value-added of this more complex portrait of vulnerability compared to a simpler scheme that is based solely on physical expo-

Figure 6.



sure and population. By subtracting a map of the first two baskets from the final composite map, we can show which places on the continent become more (or less) vulnerable when we add indicators from the final two baskets: household and community resilience and governance and political violence. Based on this difference map, the Mediterranean coastline appears far less vulnerable when we incorporate measures of resilience and governance, whereas parts of Niger, Somalia, South Sudan, and Sudan appear far more vulnerable, given their low levels of resilience and poor governance (see online maps appendix).

How robust are these findings to different weights for the baskets? Although the assumption of additive, equally weighted baskets makes computation straightforward, it is both a convenience and a simplification. In the absence of substantive theoretical reasons to change the weights, however, the equal weight assumption is common among composite indices.[67] That said, we assess the stability of our findings by altering the weights. To the extent that some areas remain in the top quintile of vulnerability across multiple specifications, these areas constitute important regions of concern. We created four alternative sensitivity analyses of our models, increasing the weight of one of our four baskets to 40 percent with the other three equally weighted at 20 percent (see online maps appendix for four maps each overweighting one basket). This map reveals that the countries and subregions of concern remain consistent across various models' weights. Figure 7 shows a core hot spots map of areas that remained in the fourth and fifth quintiles of highest vulnerability across all four models, where one basket is weighted at 40 percent and the others are weighted at 20 percent.

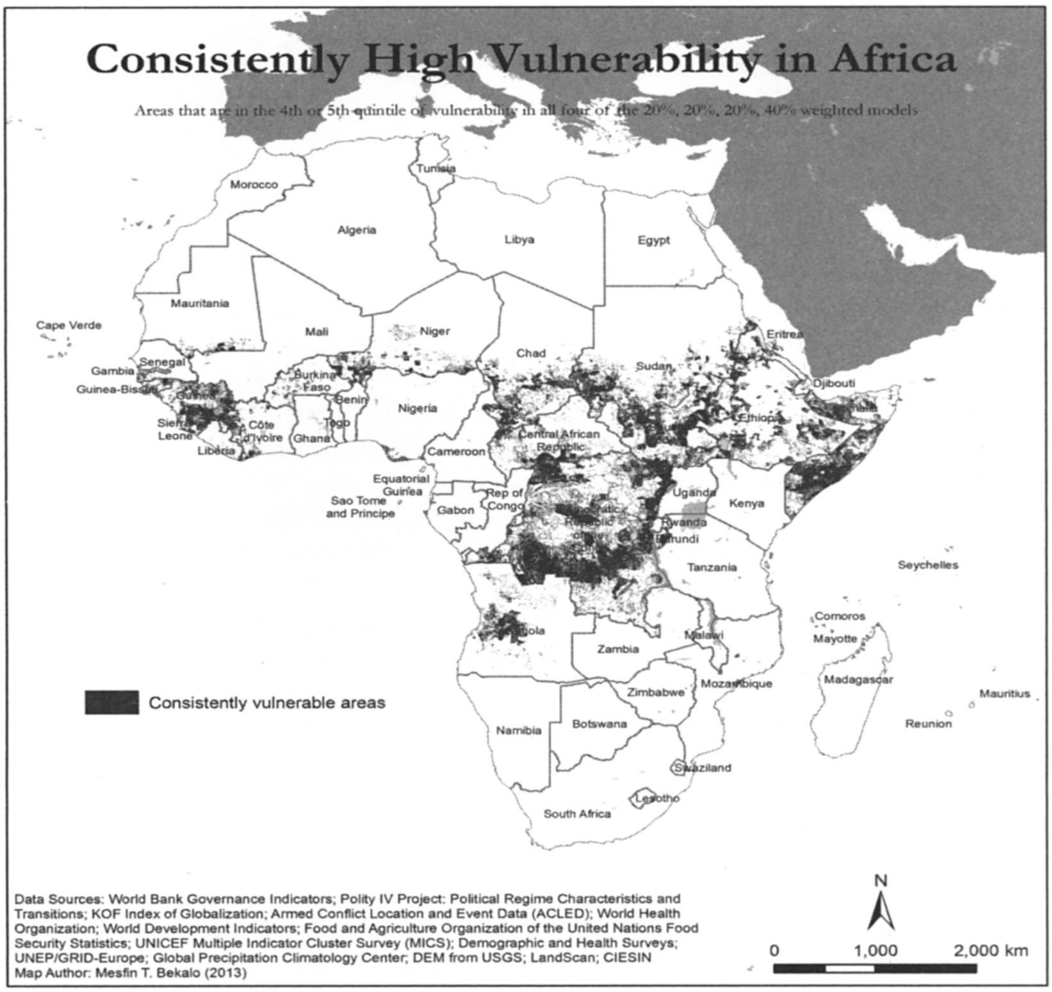
Our approach also permits examination of the drivers of vulnerability, which in turn can inform appropriate policies and interventions. From figure 6, we selected four areas of high overall vulnerability for more fine-grained analysis, including the DRC, Guinea and Sierra Leone, Somalia, and Sudan/South Sudan, all of which were also in Wheeler's top twenty-five most vulnerable countries. The online table of fifth quintile vulnerability shows the relative contribution of each basket to the overall vulnerability scores for the areas in the fifth quintile of vulnerability as well as the percentage of populated areas located in that most vulnerable quintile.

The DRC had more than 26 percent of its populated areas in the fifth quintile of vulnerability, with high vulnerability driven principally by low resilience and poor governance. In terms of physical exposure, over the last couple of decades the DRC was, by the measure of drought we used, particularly drought prone in the North, while especially fire prone in the South.[68] Like Somalia, an end to conflict and basic governance capacity are high-priority policy areas.

67. Two other climate vulnerability indices are available from Maplecroft and One World Trust. See Maplecroft, *Climate Change Vulnerability Index,* http://www.maplecroft.com/themes/cc/; and Rob Davies and Stephanie Midgley, *Health and Food Security Risk Profile Mapping in Southern Africa* (Cape Town, South Africa: One World Sustainable Investments, 2009).

68. Given that the EM-DAT database reports no drought disasters in the DRC during the period 1995–2008, we find this particular result a little puzzling. Our findings on droughts are consistent with Theisen, Holtermann, and Buhaug, "Climate Wars?" That said, we have reasons to question the drought data, which are based on rain gauge collection, the numbers of which have declined precipitously in Africa over the last two decades. For a critique of measures of drought, see Bradfield Lyon, *Quantifying Drought: Some Basic Concepts,* memo for the "Mapping and Modeling Climate Security Vulnerability" workshop, Lyndon B. Johnson School of Public Affairs, University

Figure 7.



Nearly 30 percent of the fifth quintile vulnerability scores were driven by the governance basket (see online maps appendix for pullout maps of the DRC).

The West African countries of Guinea and Sierra Leone are particularly vulnerable to climate security concerns. More than 6 percent of Guinea's area is located in the most vulnerable fifth quintile, while more than 10 percent of

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of Texas, Austin, 2011, http://strausscenter.org/images/pdf/climateworkshop/lyon_memo_for_web.pdf.

Sierra Leone's populated area is located in the fifth quintile. Although the specific sources of vulnerability in fifth quintile areas were nearly evenly divided across all four baskets, high population density and low resilience were narrowly the most important sources of both countries' areas of highest vulnerability. Guinea and Sierra Leone were both in Wheeler's top twenty-five most vulnerable countries in the world. Their physical exposure was largely a product of wildfires, droughts, and, in the case of Sierra Leone, low elevation coastal zones (see online maps appendix for pullout maps of West Africa). For both, investments in health to improve local community resilience are among the priority policy areas.

Somalia has the largest amount of its populated area in the fifth quintile of any country in Africa (nearly 30 percent). While its physical exposure is moderate (rooted mostly in drought and persistently scarce rains), its particular vulnerability is largely the result of low resilience and terrible governance. In Somalia, 30 percent of the country's overall vulnerability score is driven by low household resilience and governance scores, respectively. Given the continued absence of a functioning government, Somalia ranked highest in both our composite index and Wheeler's. Its most vulnerable areas are located in and around the capital Mogadishu and the far north of the country.[69] From a policy perspective, basic governance and stability have to be the highest priorities, as few other things can be done in the interim (see online maps appendix for a series of pullout maps of Somalia). South Sudan, having voted for independence in 2011, may find itself facing intense challenges associated with climate change. More than 11 percent of pre-partition Sudan's populated areas were in the fifth quintile of vulnerability.[70] Governance and physical exposure (primarily from drought, persistent scarce rains, and fire) were the main drivers of Sudan's vulnerability, responsible for 31 percent and 27 percent of the overall vulnerability score for the fifth quintile areas of then unified Sudan (see maps appendix for pullout maps of Sudan and South Sudan). As the new South Sudan government gets established, donors could help by investing in early warning systems, fire protection, rainwater collection, and other measures to build capacity and to protect against water scarcity. That said, the government, faced by intense security competition with Sudan in 2012, may face existential challenges for some time.

Although not explicitly discussed, other pockets of high vulnerability exist in Angola, Burundi, Eritrea, Ethiopia, and Niger, where low scores on human

69. In the north, the relatively more effective governance in Somaliland is not reflected in the maps, as it is not recognized as a legitimate government.
70. It should be noted here that, while the border between Sudan and South Sudan is shown in the maps, the national-level household and community and governance data used in the index construction are from data reported for Sudan prior to South Sudan's independence.

development coincide with poor governance indicators and considerable disaster risk from droughts, scarce rain, and fires. As the online table of fifth quintile vulnerability demonstrates, most of these countries experienced a number of disasters in the 1995–2010 period and were among Wheeler's most vulnerable countries.

Extensions for Further Research

Maps of vulnerability are only points of departure rather than end-states of analysis. They are meant to prompt conversation and further research. Maps greatly simplify a complex reality and require narratives to properly interpret them. Having provisionally identified the places of greatest subnational vulnerability within Africa, scholars need to understand more about the historical and political dynamics of those places and how they intersect with exposure to historic climate-related hazards and climate change. Ultimately, policymakers dealing with the effects of climate change will need guidance about where to prioritize their resources. Although these maps are not the definitive answer to that question, they provide an important resource to begin the dialogue about where to focus attention.

That said, the maps have their limitations and require further refinement. For a number of indicators, particularly those for household resilience and governance, we had to use national-level data in the absence of subnational data. Subsequent iterations will attempt to acquire more localized data as these become available. We are in the process of creating additional subnational indicators for literacy and school enrollment, and we are aiming to identify more subnational governance indicators.

In addition, most of the physical vulnerability data in this article are based on past disaster frequencies and intensities. The next iteration of our research incorporates models of future climate change risk. Heretofore, models of future African climate change, at least for some areas such as the Sahel, appeared to have had wildly divergent predictions with respect to rainfall and other indicators.[71] More recent research, however, suggests that these discordant findings may be a product of problems in downscaling global climate models. Christina Patricola and Kerry Cook have constructed a regional climate model for North Africa above the equator (excluding North African countries on the Mediterranean coast).[72] They argue that their findings better explain past cli-

71. Boko et al., "Africa"; and Gulledge, *Scientific Uncertainty and Africa's Susceptibility to Climate-Driven Conflict.*
72. Christina M. Patricola and Kerry H. Cook, "Northern African Climate at the End of the Twenty-First Century: An Integrated Application of Regional and Global Climate Models," *Climate Dynamics*, Vol. 35, No. 1 (July 2010), pp. 193–212.

mate patterns and important attributes, such as the West African monsoon, than previous climate prediction models. We have collaborated with Cook to extend the regional model to be continent-wide and to focus on time scales relevant for policymakers—mid-twenty-first century—rather than late twenty-first century, as is the norm among climate modelers.[73] Our ongoing collaboration with climate modelers represents a way to triangulate the data to see if the areas of projected future exposure correspond to the areas historically exposed to climate-related hazards. These same climate projections have allowed us to generate late twentieth-century simulations of extreme weather events, including heavy rainfall days, dry days, and heat wave events. Although imperfect corollaries with our historic climate-related hazard data, they do provide a way to compare the consistency of areas of historic exposure.

An additional extension would be to overlay geocoded data on ethnic groups. Given that recent studies suggest that ethnicity plays a strong role in African politics as a source of conflict and division,[74] ethnicity could also play a powerful role in determining future vulnerability to the effects of climate change. In some cases, ethnic groups may be 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 national-level indicator of ethnic political exclusion is available through the Ethnic Power Relations dataset, but incorporating this indicator into the index would not help us to identify where the excluded groups are located. A geocoded version of the Ethnic Power Relations (GeoEPR) dataset was published in 2010, however.[75] The data can help to

73. Kerry H. Cook and Edward K. Vizy, "Impact of Climate Change on Mid-Twenty-First Century Growing Seasons in Africa," *Climate Dynamics*, Vol. 39, No. 12 (March 2012), pp. 2937–2955; and Edward K. Vizy and Kerry H. Cook, "Mid-21st Century Changes in Extreme Events over Northern and Tropical Africa," *Journal of Climate*, Vol. 25, No. 17 (September 2012), pp. 5748–5767.

74. Although a 2003 study by James Fearon and David D. Laitin found no connection between a measure of ethnicity (ethnolinguistic fractionalization) and conflict, more recent studies have found stronger evidence supporting the notion that ethnic political marginizaliation may contribute to conflict. Fearon and Laitin, "Ethnicity, Insurgency, and Civil War," *American Political Science Review*, Vol. 97, No. 1 (February 2003), pp. 75–90; Kahl, *States, Scarcity, and Civil Strife in the Developing World;* Lars-Erik Cederman and Luc Girardin, "Beyond Fractionalization: Mapping Ethnicity onto Nationalist Insurgencies," *American Political Science Review*, Vol. 101, No. 1 (February 2007), pp. 173–185; and Lars-Erik Cederman, Luc Girardin, and Kristian Skrede Gleditsch, "Ethnonationalist Triads: Assessing the Influence of Kin Groups on Civil Wars," *World Politics*, Vol. 61, No. 3 (May 2009), pp. 403–437.

75. See Lars-Erik Cederman, Brian Min, and Andreas Wimmer, "The Ethnic Power Relations (EPR) Dataset," 2010, http://dvn.iq.harvard.edu/dvn/FileDownload/?fileId=1381624&vdcId=378&xff=0; Nils B. Weidmann, Jan Ketil Rød, and Lars-Erik Cederman, "Representing Ethnic Groups in Space: A New Dataset," *Journal of Peace Research*, Vol. 47, No. 4 (July 2010), pp. 491–499;

identify where vulnerable areas overlap with ethnic groups that have experienced historic discrimination, that are powerless, or that are politically irrelevant.[76] We thought that assigning cardinal ranks for these categories was too problematic to incorporate this indicator directly into our index. Therefore, we followed Levy et al.'s strategy of using overlays, here overlaying areas of historic ethnic political marginalization on high-vulnerability areas from our index. Space considerations do not permit a more extended discussion here, but our overlays are available in the online ethnic vulnerability appendix.[77]

Beyond the sensitivity analysis, questions remain about the external validity of these maps. Can we trust that they represent a true portrait of the underlying climate security vulnerabilities they depict? Unlike statistical findings, maps come without confidence intervals or error bars. Even if text around the maps emphasizes their provisional nature, readers may find the maps seductive in their visual simplicity and therefore potentially misleading. Establishing the external validity of the maps is the most difficult challenge for us, and one that can only be provisionally addressed in a single article. We have sought to allay readers' concerns by providing sensitivity analysis to reveal the consistency of our findings across multiple basket weights. In addition, once we prepared the first iteration of our maps,[78] we created four teams of mapmakers to test and refine the methodology for regions of Africa. We used these exercises to identify missing indicators, new data sources, and alternative approaches to visualize the data.[79]

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and Julian Wucherpfennig, Nils B. Weidmann, Luc Girardin, Lars-Erik Cederman, and Andreas Wimmer, "Politically Relevant Ethnic Groups across Space and Time: Introducing the GeoEPR Dataset," *Conflict Management and Peace Science*, Vol. 28, No. 5 (November 2011), pp. 423–437. Clionadh Raleigh assesses the relative vulnerability of ethnic groups to climate change in Raleigh, "Political Marginalization, Climate Change, and Conflict in African Sahel States," *International Studies Review*, Vol. 12, No. 1 (March 2010), pp. 69–86.

76. Lars-Erik Cederman, Halvard Buhaug, and Jan Ketil Rød, "Ethno-Nationalist Dyads and Civil War: A GIS-Based Analysis," *Journal of Conflict Resolution*, Vol. 53, No. 4 (August 2009), pp. 496–525; and Cederman and Girardin, "Beyond Fractionalization."

77. Rustad et al. developed an innovative methodology to index GeoEPR for Asian countries that we will explore in an extension of our current work. Rustad et al., "All Conflict Is Local."

78. Joshua W. Busby, Todd G. Smith, Kaiba L. White, and Shawn M. Strange, "Locating Climate Insecurity: Where Are the Most Vulnerable Places in Africa?" in Jürgen Scheffran, Michael Brzoska, Hans Günter Brauch, Peter Michael Link, and Janpeter Schilling, eds., *Climate Change, Human Security, and Violent Conflict: Challenges for Societal Stability*, Hexagon Series on Human and Environmental Security and Peace, Vol. 8 (New York: Springer, 2012), pp. 463–512.

79. Emily Joiner, Derell Kennedo, and Jesse Sampson, *Vulnerability to Climate Change in West Africa* (Austin: Robert S. Strauss Center for International Security and Law, University of Texas, Austin, March 2012), http://strausscenter.org/ccaps/climate-vulnerability-publications.html?download=55; Sanjeet Deka, Christian Glakas, and Marc Olivier, *Assessing Climate Vulnerability in North Africa* (Austin: Robert S. Strauss Center for International Security and Law, University of Texas, Austin, August 2011), http://strausscenter.org/ccaps/climate-vulnerability-publications.html?download=54; Bonnie Doty, Erika Grajeda, Pace Phillips, and Atul Shrestha, *Vulnerability to Climate Change: An Assessment of East and Central Africa* (Austin: Robert S. Strauss Center for Interna-

We also conducted extensive fieldwork to "ground truth" or validate our maps with local experts. Members of our team conducted nearly 100 interviews throughout Africa in 2010 and 2011, with visits to Burkina Faso, Ethiopia, Ghana, Kenya, Malawi, Morocco, Mozambique, Namibia, Senegal, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe. One of the main findings of this fieldwork was the need to better account for drought-related processes. Areas of chronic water scarcity, such as parts of northern Kenya, were not captured by our principal indicator of drought, the Standardized Precipitation Index. In this iteration of the maps, we included a measure of chronic water scarcity, captured by the coefficient of variation.

Another finding of this ground truthing work was that the national-level governance indicators help to contribute to sharp discontinuities in vulnerability between countries. In some cases, this may be justified. For example, the borders between Kenya and Somalia or between Uganda and South Sudan may actually represent an important demarcation in the resources available to the populations on either side. That said, even in this example we might imagine that populations farther from the national capital experience decay in the reach of their governments, and that populations on either side of an international border may be more similar to each other than the stark boundaries we observe in this iteration of our maps. We attempted to incorporate some proxies that begin to get at this problem, such as roads and other infrastructure, but standardized data sources for all of Africa were found wanting. Given that the ACLED data are the single subnational governance indicator in this iteration of our work, this is another area for future research.[80] Indeed, with our governance and political instability indicators based on data that preceded the Arab Spring, there are other difficulties in representing chronic governance challenges on a static map in a highly fluid situation.

Beyond this ground truthing exercise, we also expanded and revised our mapping work and indicators based on extensive conversations with other vulnerability mappers, including consultations with scholars and practitioners from CIESIN, the United Kingdom's Department for International Develop-

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tional Security and Law, University of Texas, Austin, August 2011), http://strausscenter.org/ccaps/climate-vulnerability-publications.html?download=53; and Sachin Shah, Sarah Williams, and Shu Yang, *Water Resource Stress and Food Insecurity in Southern Africa* (Austin: Robert S. Strauss Center for International Security and Law, University of Texas, Austin, August 2011, http://strausscenter.org/ccaps/climate-vulnerability-publications.html?download=52).

80. Jared Berenter, *"Ground Truthing" Vulnerability in Africa*, CCAPS Research Brief, No. 4 (Austin: Robert S. Strauss Center for International Security and Law, University of Texas, Austin, May 2012), http://strausscenter.org/ccaps/climate-vulnerability-publications.html?download=89; and Jared Berenter, *"Ground Truthing" Vulnerability and Adaptation in Africa* (Austin: Robert S. Strauss Center for International Security and Law, University of Texas, Austin, March 2012), http://strausscenter.org/ccaps/publications/reports.html?download=91.

ment, the Famine Early Warning Systems Network, the Food and Agriculture Organization, the International Organization for Migration, IRIN News, the National Aeronautics and Space Administration, the National Center for Atmospheric Research, the United Nations Environment Programme (UNEP), the United Nations High Commissioner for Refugees, the United Nations International Strategy for Disaster Reduction, the United States Agency for International Development, the World Bank, and the World Food Programme.[81]

In addition to these efforts, we have created a tool that allows users to visualize different aspects of the data. In the tool's current iteration, the basket weights are preset to be equal, but in an upcoming extension, users will be able to manipulate the basket weights based on their own assumptions and prior understandings.[82] We continue to explore new data sources and means to triangulate our maps with measures that could establish their external validity. For example, the Famine Early Warning Systems Network has produced maps of seasonal famine risk for numerous African countries for nearly two decades. Although country coverage and methods have changed, there is some scope for identifying chronic famine-prone areas, potentially allowing us to compare them with areas of chronic climate security vulnerability. In addition, although the EM-DAT database has not been comprehensively geocoded,[83] there is potential to identify the areas where disasters have led to the greatest number of affected populations and deaths. To the extent that these areas correspond to the fifth quintile areas of climate security vulnerability, we can be more confident that our maps represent reality.

More statistically inclined readers might be surprised to learn that the composite map figure 6 is not based on an underlying econometric model. Many composite indices in the field, such as the Freedom House index or the Ibrahim Index of African Governance, do not have an econometric basis and are externally validated in other ways, such as expert opinion or fieldwork.[84]

81. In May 2011, we convened a conference on the methodology of vulnerability mapping. See Joshua Busby and Jennifer Hazen, *Mapping and Modeling Climate Security Vulnerability: Workshop Report* (Austin: Robert S. Strauss Center for International Security and Law, University of Texas, Austin, October 2011), http://strausscenter.org/ccaps/climate-vulnerability-publications.html?download=47.

82. CCAPS and AidData, dataset, http://ccaps.aiddata.org/.

83. We did geocode the drought disasters in EM-DAT for use in our statistical modeling. See the online statistical appendix for more discussion.

84. For Freedom House's methodology, see Freedom House, "Freedom in the World, 2011: Methodology" (Washington, D.C.: Freedom House, 2011), http://www.freedomhouse.org/report/freedom-world-2011/methodology. For the Mo Ibrahim index methodology, see Mo Ibrahim Foundation, *Methodology* (London: Mo Ibrahim Foundation), http://www.moibrahimfoundation.org/IIAG-methodology/.

Even if an econometric analysis were desirable, time-series subnational data for Africa is extremely limited, particularly for social and political indicators. As we note in the methodological appendix, household surveys have been carried out sporadically across Africa, with different countries surveyed in different years, making it challenging to build a dataset. We have made an effort to bootstrap an econometric model as an extension of our original work, but the project started as a geospatial mapping exercise drawing on research traditions and foundations other than econometrics.[85]

The effort has proved challenging. Our prospective dependent variable is the percentage of the population affected by climate-related disasters from the EM-DAT database. Although its founders and others have experimented with different approaches to geocode their database for nearly a decade, it has not been comprehensively geocoded (though we have made an effort to do so for droughts for this article). In the EM-DAT data, the geographic field for location of disasters is not precise and in many instances is missing. At best, some events have specified provincial locations, but these are applied inconsistently. Whether EM-DAT can be geocoded is subject to much academic debate that goes beyond the scope of this article.[86]

That said, other studies have demonstrated the challenges of using EM-DAT for statistical purposes. The 2009 UNISDR global assessment on disasters assesses the statistical significance of different factors to individual kinds of disasters to explain disaster mortality and disaster losses. Given the lack of geocoded data, the analysis was conducted at the national level. Consistent with the Brooks, Adger, and Kelly study, UNISDR's study contained a number of 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. Whereas the correlations between mortality and earthquakes, volcanoes, and a number of other indicators largely yielded results consistent with expectations, the correlations between drought and mortality were inconclusive, leading the authors to reappraise their entire approach to drought.[87]

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85. Rustad et al. similarly found that the lack of data availability made it impossible to develop a subnational conflict prediction model. Instead, they allow users to manipulate the weights attached to particular indicators. Rustad et al., "All Conflict Is Local Modeling Sub-National Variation in Civil Conflict Risk," p. 18.
86. Debarati Guha-Sapir, Jose M. Rodriguez-Llanes, and Thomas Jakubicka, "Using Disaster Footprints, Population Databases, and GIS to Overcome Persistent Problems for Human Impact Assessment in Flood Events," *Natural Hazards*, Vol. 58, No. 3 (March 2011), pp. 845–852; and P. Peduzzi, H. Dao, and C. Herold, "Mapping Disastrous Natural Hazards Using Global Datasets," *Natural Hazards*, Vol. 35, No. 2 (June 2005), pp. 265–289.
87. See Pascal Peduzzi, B. Chatenoux, H. Dao, A. De Bono, U. Deichmann, G. Giuliani, C. Herold, B. Kalsnes, S. Kluser, F. Løvholt, B. Lyon, A. Maskrey, F. Mouton, F. Nadim, H. Smebye., *The Global*

Nonetheless, in an effort to further allay the concerns of our readers, we sought to statistically test the strength of the indicators in our baskets as predictors of outcomes by using the number of people affected by disasters as a dependent variable. This is similar to the UNISDR study as well as to work at the national level by Timmons Roberts and Bradley Parks, Brooks, Adger, and Kelly, and Wheeler. Such analysis can potentially be done for multiple hazards or for individual hazards. Here, the subnational unit of analysis is level-one administrative units using the Global Administrative Areas classification scheme.[88] As we noted, given the subnational focus of our project, our index was constructed using indicators with whatever data were available. Some data sources, particularly some of the household indicators, are available only for individual years, often not the same year for different indicators. We sought to create a time-series dataset by interpolating missing data for certain indicators.

We were not able to geocode all types of EM-DAT climate-related disasters. Yearly, geospatial data are not available for a number of the different climate hazards, such as floods, for proprietary reasons. As a result of these challenges, we constructed a dataset taking the number of people affected by droughts (using data from the EM-DAT dataset) and using data from UNEP on physical droughts as one of the independent variables. As the UNISDR study experienced, our statistical results are inconclusive. Some of the indicators are statistically significant, with the coefficient having the expected direction. For example, the percentage of the population with access to an improved water source is negatively correlated with disaster-affected populations, meaning that if more people have access to safe drinking water, the probability of a drought disaster occurring is lower, and a lower percentage of the population is affected in the event of drought disaster. Other indicators, however, do not have the appropriate signs or are not statistically significant. For example, the coefficient and significance determination for hospital beds (per 1,000 people) is sensitive to model specification. This finding is contrary to that of Brooks, Adger, and Kelly and may be the result of bias from any or all of three sources. First, data that are systematically missing can bias the results. There is reason to believe that countries with less robust health-care systems would also be lacking in national capacity to report to international agencies about their health-care systems. Second, there may be considerable measurement error

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Risk Analysis for the 2009 Global Assessment Report on Disaster Risk Reduction (Davos, Switzerland: International Disaster and Risk Conference, 2010), http://www-fourier.ujf-grenoble.fr/~mouton/Publis_HDR_applis/Peduzzi-The_Global_Risk_Analysis_for_the_2009_GAR-149.pdf.

88. Global Administrative Areas (GADM), "GADM Database of Global Administrative Areas," *Global Administrative Areas*, 2012, http://gadm.org/.

based on (1) national aggregation of indicators that in reality exhibit substantial subnational variation; and (2) inaccurate time-series interpolation of missing data. Third, there is a potential reporting bias in the EM-DAT database, given that more robust health-care systems enable improved monitoring of mortality and morbidity during disasters.[89]

Ultimately, we should not be surprised that the statistical analysis is inconclusive. We have unsatisfactory data to work with, including missing data, problematic indicators of drought, and only limited geocoded data on dependent variables of interest. As better time-series data of the type currently being produced by USAID's Demographic and Health Surveys become available,[90] we hope in time that we will be able to further validate our indices through statistical work, but this may be a dead end until more expansive and appropriate geocoding of EM-DAT is available. That said, the incompleteness of the statistical support for our approach should not detract from the promise and potential of this project. As we have tried to show, there are other ways to establish the external validity of the maps.

Conclusion

This article represents the accumulation of three years of mapping, fieldwork, and conversations with other scholars. We hope that it will prompt a vigorous response about how climate security vulnerability should be modeled and validated. It is intended to be a proof of concept for mapping subnational climate security vulnerability. The more holistic approach outlined here can provide guidance to policymakers within Africa and internationally as they work to identify the places in Africa most vulnerable to climate change. By identifying subnational geographic areas of interest, we hope that our work can help policymakers to tailor adaptation strategies and distribute scarce resources to the places in Africa where the need is greatest, and ultimately to help countries to prepare for and to minimize the security consequences of climate change.

89. The online statistical appendix provides more detail on these findings.
90. USAID, "MEASURE DHS Demographic and Health Surveys" (Calveton, Md.: Measure DHS, 2012), http://measuredhs.com/.