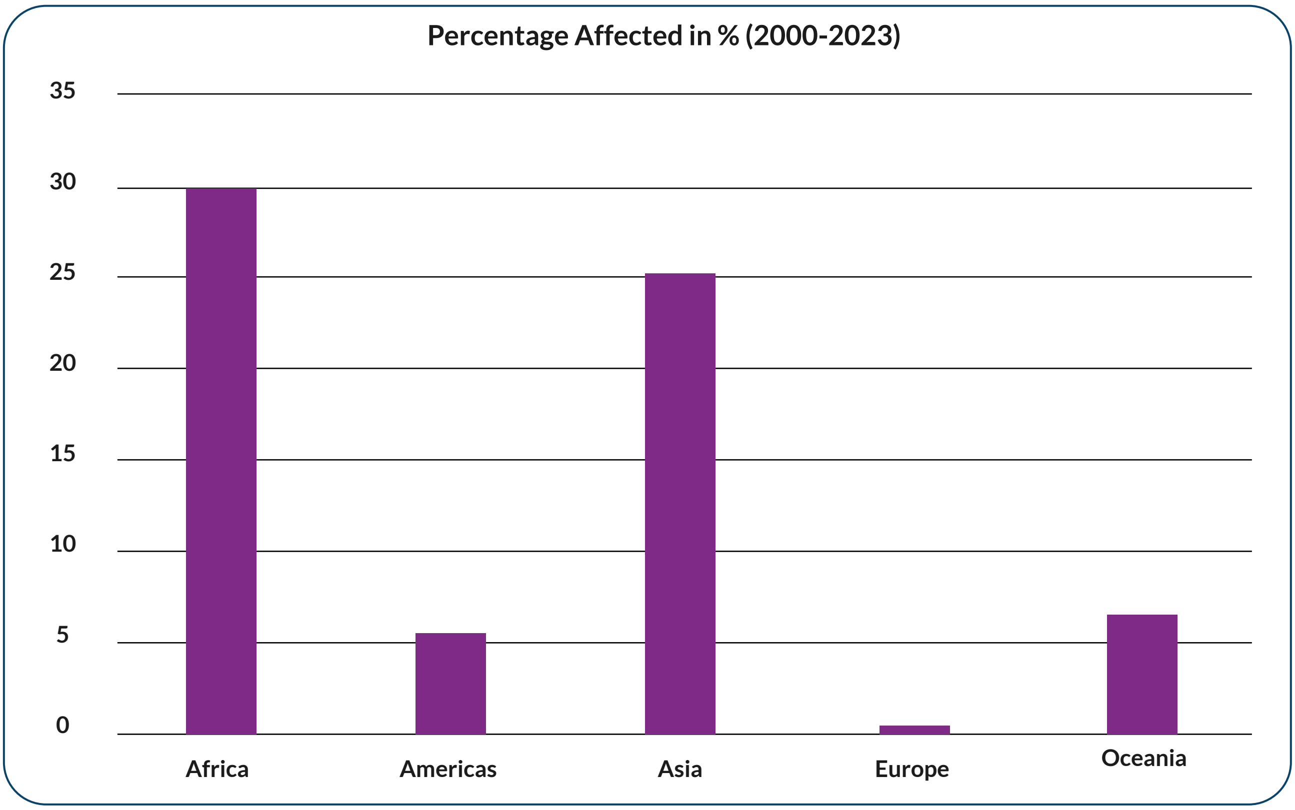
NOTE 5d

Drought Risk Modeling

Drought-related shocks can have long-term impacts on ecosystems, agriculture, and human society. Between 2000 and 2023, Africa experienced more reported drought events than any other continent[1]. During this period, droughts affected more than 418 million people in Africa and more than 1.18 billion in Asia. In other words, one in four Asians and one in three Africans experienced drought conditions during the last 23 years (Figure 1). The socioeconomic impacts of droughts can have far reaching implications, with long term impacts on people's physical development, education and lifetime earnings, and ultimately on countries' development gains and economic prospects.

Figure 1: Percentage of population affected by drought, 2000–2023



Source: EM-DAT: The International Disaster Database, https://www.emdat.be/.
Note: The percentages shown are likely underestimates.

Low-income countries are disproportionately impacted by drought[2]; extreme droughts reduce GDP growth in such countries at approximately double the rate of high-income countries. While high-income countries may suffer minor growth reductions from extreme droughts, low-income countries face significant economic setbacks from both moderate and extreme drought events.

[1] Statistics are as of November 2024 and are taken from EM-DAT: The International Disaster Database, https://www.emdat.be/.
[2] Esha Zaveri, Richard Damania, and Nathan Engle, "Droughts and Deficits: Summary Evidence of the Global Impact on Economic Growth," World Bank, Washington, DC, 2023.
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Why Model Drought Risk?

Droughts, and their impacts on people and economies, typically develop over time. There is thus an opportunity to intervene in the chain of impacts with targeted agricultural, social protection, or risk finance solutions such as insurance. Too often, however, such programs are unable to prevent catastrophic impacts on the most vulnerable. This is partly because they are insufficiently financed, and partly because the drought risk data needed to inform their design and operation are lacking. This lack of data can also make risk financing programs, such as insurance, more expensive.

Drought risk develops very differently from the risk of other perils considered in this knowledge series (tropical cyclones, for example, affect physical assets over a short time period). Drought's impacts also differ from those of other perils. Thus drought risk analytics and modeling techniques differ from those used to model other risks, and also reflect a range of different approaches. The techniques and data that can be used to understand drought risk vary substantially depending on the context, application, and type of drought. For this reason, and because the international insurance markets have not had the same focus on drought as on perils such as tropical cyclones, drought models are typically not purchased or licensed from large risk modeling vendors. Nevertheless, there exists a range of standard, exploratory, and proprietary methods to analyze drought risk and inform risk financing and other drought risk management.

What Can Be Modeled?

There is no single definition of a drought. Drought can refer to meteorological drought (unusually low rainfall), agricultural drought (drought leading to crop failure), or socioeconomic drought (where water supply is too low to support human and environmental needs). Depending on the drought of interest, the intervention or decision being considered, the context, and the data available, different subjects can be analyzed and modeled:

Meteorological drought:

Modeling typically focuses on precipitation data, soil moisture levels, evapotranspiration, temperature, and other climatic variables that can be measured using ground sensors or estimated using satellite data. Sometimes drought analysts and risk finance practitioners use drought hazard as a proxy or early warning for agricultural or socioeconomic drought, accepting reduced accuracy in return for simplicity, speed, scalability, and low cost.

The ground sensors or weather stations that provide the climatological data used in drought modeling may be managed by national hydrometeorological agencies or may be available from satellite data providers, such as the European Space Agency (ESA), the National Aeronautics and Space Administration (NASA), or commercial operators. Some data are available as commonly used standard products such as CHIRPS (Climate Hazards InfraRed Precipitation with Station) data and ERA rainfall data sets.

Agricultural drought:

Effects on crops, livestock, and food security are analyzed using weather, soil, and agricultural data. These are derived from several sources: observations of crop performance (based on in situ measurement or estimated using satellite imagery), models that estimate the crop performance based on climatological conditions (such as level and timing of precipitation), data on which crop types are grown where (i.e., exposure data), and scientific understanding of crop phenology. These data are crucial for understanding economic and human impacts.

Data that support understanding of drought impacts on crop yields and food insecurity include the following:

- Combined drought indexes, which may be a valuable resource to build understanding of drought risk in some contexts. Examples include the Standardized Precipitation and Evapotranspiration Index (SPEI), the Water Requirement Satisfaction Index (WRSI), and the Composite Drought Indicator (CDI).
- Vegetation satellite data, such as the Normalized Vegetation Difference Index (NDVI), which measures the level of "greenness."
- Crop production or yield data, available from government agencies such as departments of agriculture, or from international organizations such as the Food and Agriculture Organization of the United Nations (FAO).
- Food insecurity estimates from government or international agencies such as IPC (Integrated Food Security Phase Classification), Cadre Harmonisé, and FEWSNET (Famine Early Warning System Network); or other food insecurity–related data from international organizations such as the World Food Programme WFP (in particular its Vulnerability Analysis and Mapping [VAM] data).

Socioeconomic drought:

Econometric or statistical techniques can be used to estimate the impact of meteorological or agricultural drought conditions on people and economic activity. This typically requires detailed data on populations (e.g., microeconomic survey data) or local economic activity.

Which types of drought risk models exist?

Various modeling approaches exist that use hydrometeorological and other data to better understand drought and its impact. These vary widely depending on the context and use to which they are put:

Deterministic models are most commonly used in the area of drought risk finance and index insurance. They consider the extent of drought based on the level of inputs such as precipitation or soil moisture. They may use a simple threshold-based approach, calibrated based on historical experience or scientific understanding of the phenology of key crops. This is the approach used in the WRSI (which is the basis of the drought insurance product of the African Risk Capacity). Deterministic models can then be applied to a range of historical and/or potential hydrometeorological conditions to give an indication of how (modeled) droughts vary and ultimately to build an understanding of risk.

Statistical models, such as Autoregressive Integrated Moving Average (ARIMA) models, analyze historical data to predict future trends. These models can be useful tools but are limited by their complete dependence on the past to predict the future; moreover, their accuracy depends entirely on the quality of data provided as inputs. Such models have been tested to support risk financing mechanisms, such as those focused on food insecurity response, with mixed success.

Probabilistic models use techniques such as Monte Carlo simulations, Markov chains, and Bayesian networks to explore diverse drought scenarios and uncertainty in modeling. Due to the complexity of drought and the inconsistency of data on which to build such models, these models remain at the frontier of drought modeling.

Box 1.
De-risking, Inclusion, and Value Enhancement of Pastoral Economies in the Horn of Africa (DRIVE) Project

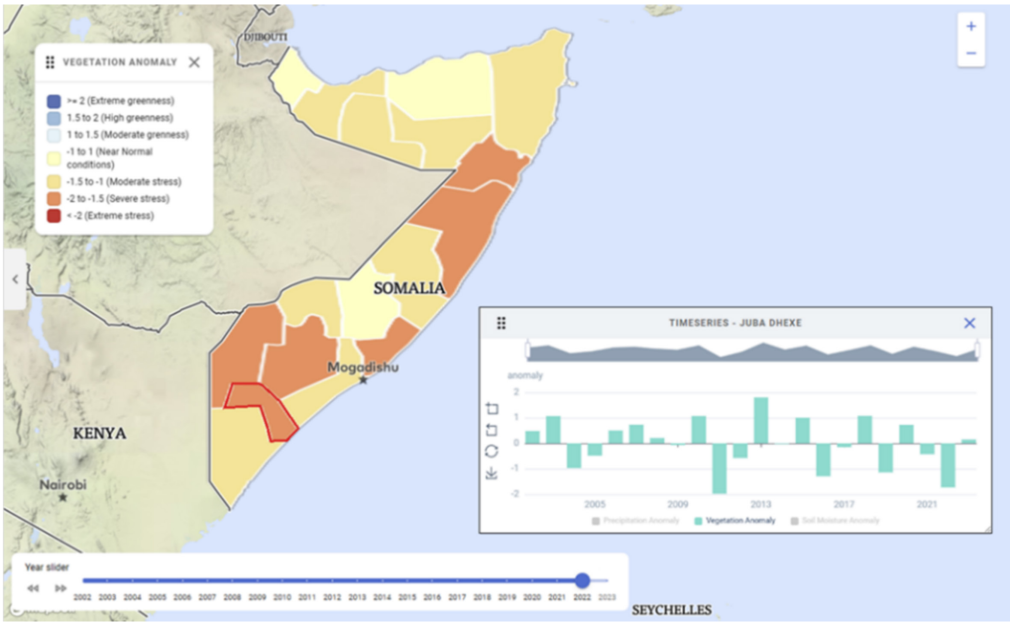
Droughts have a profound impact in the Horn of Africa, in particular in Ethiopia, Kenya, and Somalia. Droughts cause the death of pastoralists' livestock—which represents their livelihood, nourishment, and wealth—and traps households in poverty. The De-risking, Inclusion, and Value Enhancement in the Horn of Africa (DRIVE) project breaks this pattern by building pastoralists' financial resilience to droughts through insurance and financial services.

DRIVE strengthens the resilience of pastoralist communities to climate shocks, particularly droughts. A cornerstone of the project is an insurance product that pays pastoralists when the availability of pasture (measured NDVI, based on satellite data observations of vegetation cover) falls too low. This product provides pastoralists with the money needed to keep their animals alive (a solution that is five times cheaper than replacing them); it thus makes livestock value chains more attractive for investment and ensures that families and businesses can prosper.

DRIVE relies on high-quality data and analytics to meet pastoralists' needs. Governments, Zep Re (the project implementer and regional insurer), and the World Bank must understand when and where droughts happen, and what their impacts are, in order to ensure that insurance is cost-effective and pays pastoralists when they need it. This information also helps ensure that reinsurers are charging the right price, that the insurance product is designed appropriately, and that it is continuously improved. Finally, it makes it possible to understand and communicate when the product is performing well and when it is not, and to make sure that the most suitable data are being used.

The World Bank's Next Generation Drought Index (NGDI) Dashboard has supported the ongoing development and monitoring of drought risk and the insurance product's performance. The dashboard provides a visualization of multiple climate indexes—rainfall, soil moisture, and vegetation health—and related payouts through time. It allows stakeholders to explore climate data and compare them to real-world conditions on the ground. This transparency has built trust in the insurance product, as stakeholders can scrutinize whether conditions on the ground align with the thresholds set for insurance payouts. In Somalia, for instance, the dashboard helped explain why insurance thresholds had not been breached in certain regions, and thus why no payment had been made to pastoralists.

Figure 2: Sample NGDI Dashboard visualization for Somalia



Source: World Bank Disaster Risk Finance and Insurance Program, NGDI Dashboard, http://ngdi.financialprotectionforum.org/.

Challenges and Future Directions

For drought, the causal relationships with socioeconomic impacts are often less evident than they are for other climate shocks. Although crop health and development are often directly related to climate conditions and can be monitored via satellites, they are also influenced by many other factors, such as diseases, locusts, or crop variety. Public statistics provide only national estimates, which are insufficient to tailor a subnational drought risk finance product. Crop-cutting experiments (in-person measurements of crop yields) can solve this issue, but are expensive to carry out at scale. It is therefore crucial to incorporate the expertise of national experts or communities and leverage multiple data sources to assess the impact of drought shocks accurately. Meanwhile, the use of technology to measure and understand drought risk is improving rapidly; frontier areas include the use of AI and photographs of crops to measure crop yields, as well as application of large language models to traditional and social media to assess drought impacts on crops, households, food security, and economies.

The indirect impacts of drought are very challenging to quantify, in particular those on human health and mortality. For example, though droughts are often a major contributor to deaths among vulnerable food- and water-insecure populations, they are not the only contributor. Thus the classification of drought and its impacts is much more complex than for fast-onset disasters like earthquake, where the impact is well defined and is observed and recorded over a short period of time. As a result, droughts can be underrepresented in disaster databases or misclassified under “complex crises.” The consideration of long-term impacts, such as the impact of droughts on people’s physical development or wealth generation, is an emerging field.

Key to effective drought risk management and financing is a strong understanding of the dynamics of drought, which empowers countries to assess and manage drought risks effectively. Capacity building and targeted knowledge transfer are thus crucial alongside investments in strengthening data collection and drought risk analytics. The World Bank’s Next Generation Drought Index (NGDI) Dashboard aims to address this need through an intuitive visual tool that allows users to view and interrogate drought risk, understand its impacts, and explore how risk financing products may perform to respond to shocks.

FAQs

What is “non-stationarity” and what does it mean for drought risk?

The hydrological cycle's non-stationary nature means that drought risk changes with time, due to natural cycles, climate change, and other anthropogenic factors such as land use. For this reason, historical data may not always reliably forecast future drought patterns. There is a need to update planning tools, models, and decision support systems.

What is a “convergence of evidence” approach and how can it lead to the development of more robust financial products?

Satellite-derived or modeled climate estimates might deviate from real-world conditions due to technical issues (e.g., related to a satellite sensor), biophysical issues (e.g., depending on the land cover or topography), or algorithmic issues. Convergence of evidence refers to a situation in which analysis of spatial and temporal patterns across observations of complementary measurements shows these measurements supporting one another. If, for instance, independent observations of rainfall, soil moisture, and vegetation health largely agree regarding the detection of drought conditions over long periods (> 15 years), it can be assumed that the patterns identified by these three variables are more robust than each variable individually.

How can machine learning be used to enhance the quality of an index?

Machine learning (through random forests, neural networks, or gradient boosting) can enhance the quality of a drought index by identifying and modeling complex relationships between multiple variables. Random forests are well suited for handling high-dimensional data. Gradient boosting improves accuracy by iteratively correcting previous errors. Neural networks excel at capturing nonlinear relationships and are especially useful for spatial drought predictions because they can leverage large data sets such as satellite imagery. The ability of these models to detect intricate patterns in the data, and to provide robust and reliable predictions even in the presence of noise, makes them powerful tools for drought risk modeling. However, their effectiveness will always be limited by the quality of the data used to trhain and run the models, underscoring the critical need for substantial investment in on-the-ground data.

Reading List and Resources

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