

## OPINION

# Can we calculate drought risk... and do we need to?

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There is growing interest in the possibility of global analysis of drought risk, following the rapid development of global models of flood risk and other natural hazards. While this is an attractive idea, we argue that it is not actually possible as, unlike for flooding, it is not possible to unambiguously distinguish between “drought” and “nondrought” events, in particular when considering the impacts of droughts on agriculture. Any definition of a drought event depends upon the choice of drought index, which is to some extent arbitrary. Nonetheless, the absence of unambiguous quantified estimates of drought risk need not be an obstacle to rational drought risk management, as it is still possible to evaluate and compare the benefits of different drought risk management options.

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Science of Water > Water Extremes

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agriculture, drought, risk

Droughts are natural hazards with very widespread impacts. Drought in the Horn of Africa in 2010 and 2011 resulted in crop failure with catastrophic consequences: 15 million people in Somalia needed food aid, 350,000 refugees crossed the border into Kenya and about 260,000 people died of starvation between April 2010 and July 2012, of whom half, about 130,000 were children under 5 years of age (Slim, 2012). Droughts in Russia in 2010 cut grain yields in the Russian Federation by a third compared to the previous year (World Bank, 2018); grain exports were banned in August of that year leading to spike in global wheat prices that had knock-on effects around the world. Drought in Californian is estimated to have resulted in total economic losses of \$2.2 billion in 2014 (AghaKouchak, 2015). Despite these very visible impacts, an unambiguous definition of a drought, which would form the basis for quantified drought risk analysis, has proved to be illusive.

Quantified risk analysis involves estimating the probability and consequences of harmful events (hazards). For many damaging natural hazards, notably floods, earthquakes and hurricanes, risk analysis has grown into a global industry. Calculations of global flood risk abound (Ward et al., 2013). Models of these catastrophes are widely used, especially by the insurance industry. Risk analysis also forms the basis for targeting investments in protection (e.g., flood defenses) by governments and development banks. Analysis of these risks now not only includes the direct damage to property but also the interruption to businesses and supply chains (Willner, Otto, & Levermann, 2018) and the more intangible impacts upon people. Calculation of risk is possible because there is a well-defined baseline of undamaged assets and undisturbed socio-economic activity in the absence of the hazard. The damage relative to this baseline can be estimated for the full range of possible hazard events, from those that are barely perceptible and cause hardly any damage, through to very low probability events with catastrophic consequences. If communities adapt to the hazard, for example by zoning or enforcing building codes, then the risk will go

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down, whereas increasing hazard severity (e.g., increasing intensity of tropical cyclones due to climate change (Walsh et al., 2016)) will increase the risk.

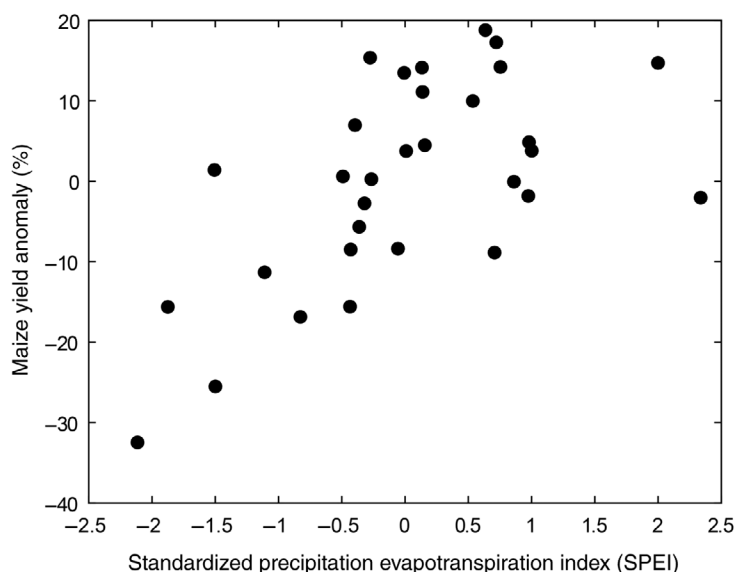
Droughts share many of the characteristics of other natural hazards, but tend to be longer events—sometimes extending over several years. Management actions during prolonged droughts modify the impacts for people and the environment (Low et al., 2015). That's also true of other natural hazard, where warnings and evacuation will reduce the impact, but because droughts last longer, there is the opportunity for more complex management actions, for example, by reducing water use, re-allocating water to different users (e.g., to ensure continued municipal water supplies by restricting water use by farmers) and transferring water from other places.

Like all natural hazards, droughts are multidimensional spatial-temporal events, but they are exceptional because of the diversity of geophysical variables that may be needed to characterize droughts: precipitation, temperature, soil moisture, river flow, groundwater levels etc. For each of these variables, there is a proliferation of drought indicators (Bachmair et al., 2016; Mukherjee, Mishra, & Trenberth, 2018), each of which defines drought in a different way and usually results in a different ranking of drought severity.

Notwithstanding this complexity, for some water users, the impacts of a drought are quite easy to define, as the counterfactual of “business as usual” water availability is obvious. For example, a thermoelectric power plant will typically have a license to withdraw a certain amount of water from a river to cool the plant (Byers, Hall, & Amezaga, 2014). The plant will have to shut down or operate at reduced load if water withdrawals are restricted during a drought. The difference in power output, and any damage to the plant incurred because of the shutdown, can readily be calculated. The drought risk to the plant can be estimated by calculating that impact across the probability-weighted range of low river flows.

For agriculture, which is the industry that is most vulnerable to droughts (Ding, Hayes, & Widhalm, 2010), calculating drought impacts is not so easy. Agricultural yields vary continuously as a function of hydro-climatic conditions, as well as being influenced by many other factors. If yields are plotted as a function of a relevant climatic variable or aggregations of those variables, for example, standardized precipitation evapotranspiration index (SPEI) (Vincente-Serrano, Beguería, & López-Moreno, 2010) or soil moisture during the growing season, not only will the data show a great deal of scatter, but there will be no intuitive cut-off between “drought” and “nondrought” conditions (see Figure 1). That contrasts to floods, where a plot of the area of crops lost due to flooding in a valley as a function of river flow may show some scatter, but it will not be a problem to distinguish the “flood” from river flows in which no flood damage occurs.

For a quantified risk analysis we need (i) to statistically characterize the hazardous event in terms of its relative severity (e.g., probability of exceedance): for droughts that is hard (because they are a multivariate spatial-temporal phenomenon) (Volpi, 2019), but feasible; (ii) quantify the consequences for any given drought event: there are many uncertainties in this process, but it is possible to approximate the impacts (Freire-González, Decker, & Hall, 2017), and (iii) estimate the consequences for a full range of drought events of varying severity: the problem here is defining the event space, that is, separating “droughts” from “nondroughts”. The definitional issue exists to some extent for all natural hazards but for the agricultural impacts of droughts it is unusually problematic because the consequences (e.g., crop loss during a drought) are so sensitive to the event definition, to a



**FIGURE 1** Maize yield anomaly in Iowa (the largest maize production state in the USA) and the growing season standardized precipitation evapotranspiration index (SPEI) for the period 1980–2010. The maize yield data has been detrended and divided by its long-term average to give the anomaly (i.e., % deviation from the average trend)

much greater extent than for other natural hazards. How can we develop evidence-based drought risk management policies given that estimates of drought risk are so dependent on unresolved questions of how to define a drought?

*Drought statistics provide worthwhile comparators*, even though there is no definitive drought metric. Indices like the Effective Drought Index (Byun & Wilhite, 1999) provide a useful metric of the relative severity of a given drought. They help to answer the question: how severe was this drought (from a meteorological perspective) compared to previous droughts? Maps showing metrics of hydro-climatic variability, like the interannual coefficient of variation of rainfall, help to illustrate parts of the world where rainfall can vary radically from 1 year to the next, implying an increased risk of multiyear droughts. Drought risk will be a particular challenge in these places, so there is a strong case for support with adaptation (Hall et al., 2014).

*Stress test sensitivity to droughts*. Stress testing involves analyzing the potential impacts of a given hazard scenario on a system. Stress testing may combine historically observed droughts with synthetic droughts sampled from statistical or physically-based models (Guillod et al., 2018). Analysis of the impacts of drought stress tests may combine evidence from past droughts, modeling (e.g., of the agriculture sector (Lesk, Rowhani, & Ramankutty, 2016) or the whole economy (Freire-González et al., 2017)) and role-playing exercises. Stress testing with droughts of a range of different severities may reveal thresholds of vulnerability (or tipping points) where the impacts become particularly severe. Stress testing of prolonged droughts will help to explore the resilience of socio-ecological systems to droughts, that is, to what extent can people and the environment cope and recover from a stressful perturbation? Large-scale analysis of relative vulnerability will help to target countries for adaptation to drought risk (Carrão, Naumann, & Barbosa, 2016).

*Prioritizing adaptation actions does not actually require calculation of drought risk*. Once vulnerable places have been identified, the next step is to prioritize adaptation actions in order to develop drought risk management plans. That might involve investing in drought warning, water supplies (including surface and groundwater storage), reducing and improving the efficiency of water use, enhancing the resilience of the natural environment, grain storage or financial instruments like index insurance (Hellmuth, Osgood, Hess, Moorhead, & Bhojwani, 2009). Usually a combination, or portfolio, of drought risk management instruments is needed. The difficult question that decision makers face is: how much of each adaptation option should be adopted and when? Economic analysis to identify the most efficient portfolio involves comparing the costs of intervention with the expected benefits of risk reduction. The expected benefit is the difference between (i) drought risk without the intervention and (ii) the smaller residual risk that we know will remain once the intervention has been implemented. These risks cannot be predicted precisely, as they are subject to a host of uncertainties, but they can be estimated with modeling and analysis. Simulation modeling provides a means of testing alternative portfolios of interventions in a wide range of drought conditions of different severities, in order to quantify the impacts. That calculation of risks, and expected benefits of alternative portfolios of interventions, does not involve defining a drought—it just involves testing a wide range of possible hydro-climatic conditions. Good instruments will be expected to cost-effectively reduce impacts in a wide range of conditions. By combining several instruments, it should be possible to establish a drought risk management policy that is robust in a wide range of possible conditions and cost-effectively minimizes the expected drought impact. The good news is that justifying a drought risk management policy does not require a precise definition of drought, even though calculating drought risk does. Though the growing trend of mapping drought indices globally provides worthwhile comparators, we believe that researchers would be more productively occupied in developing methods to probabilistically estimate drought impacts at a range of spatial scales, so they can use that information to compare drought management options and advise policy-makers on what to do.

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## CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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