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# Mapping global patterns of drought risk: An empirical framework based on sub-national estimates of hazard, exposure and vulnerability☆

Hugo Carrão *, Gustavo Naumann, Paulo Barbosa

*European Commission (EC), Joint Research Centre (JRC), Via Enrico Fermi 2749, 21027 Ispra, VA, Italy*

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ABSTRACT

A global map of drought risk has been elaborated at the sub-national administrative level. The motivation for this study is the observation that little research and no concerted efforts have been made at the global level to provide a consistent and equitable drought risk management framework for multiple regions, population groups and economic sectors. Drought risk is assessed for the period 2000–2014 and is based on the product of three independent determinants: hazard, exposure and vulnerability. Drought hazard is derived from a non-parametric analysis of historical precipitation deficits at the 0.5°; drought exposure is based on a non-parametric aggregation of gridded indicators of population and livestock densities, crop cover and water stress; and drought vulnerability is computed as the arithmetic composite of high level factors of social, economic and infrastructural indicators, collected at both the national and sub-national levels. The performance evaluation of the proposed models underlines their statistical robustness and emphasizes an empirical resemblance between the geographic patterns of potential drought impacts and previous results presented in the literature. Our findings support the idea that drought risk is driven by an exponential growth of regional exposure, while hazard and vulnerability exhibit a weaker relationship with the geographic distribution of risk values. Drought risk is lower for remote regions, such as tundras and tropical forests, and higher for populated areas and regions extensively exploited for crop production and livestock farming, such as South-Central Asia, Southeast of South America, Central Europe and Southeast of the United States. As climate change projections foresee an increase of drought frequency and intensity for these regions, then there is an aggravated risk for global food security and potential for civil conflict in the medium- to long-term. Since most agricultural regions show high infrastructural vulnerability to drought, then regional adaptation to climate change may begin through implementing and fostering the widespread use of irrigation and rainwater harvesting systems. In this context, reduction in drought risk may also benefit from diversifying regional economies on different sectors of activity and reducing the dependence of their GDP on agriculture.


## 1. Introduction

Few recurring and extreme natural events are as environmental, economic and socially disruptive as droughts, which affect millions of people in the world each year (Wilhite, 2000; Cooley, 2006). Although droughts are typically associated with aridity (Seager et al., 2007; Güneralp et al., 2015), they can virtually occur over most parts of the world, even in wet and humid regions, and can profoundly impact on agriculture, basic household welfare, tourism, ecosystems and the services they provide (Goddard et al., 2003; Dai, 2011). Recent disasters in developing and developed countries and the concomitant impacts and personal hardships

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* Corresponding author.
*E-mail addresses:* hugo.carrao@gmail.com (H. Carrão), paulo.barbosa@jrc.ec.europa.eu (P. Barbosa).

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that resulted have underscored the exposure and vulnerability of all societies to this natural hazard (Wilhite et al., 2007; Mishra and Singh, 2009). However, drought management in most parts of the world is still reactive, responding to drought after impacts have occurred (Hayes et al., 2004; Svoboda et al., 2015; Wilhite et al., 2007, 2014). This approach – commonly referred to as crisis management – is known to be untimely, poorly coordinated and disintegrated (Wilhite and Pulwarty, 2005). Moreover, the provision of drought relief or assistance to those most affected has been shown to decrease socioeconomic capabilities to face future drought episodes by reducing self-reliance and increasing dependence on government and donor organizations (Wilhite et al., 2014; Pulwarty and Sivakumar, 2014).

As a result, past attempts to manage drought disasters have been ineffective and its economic and social impacts have increased significantly worldwide (Peterson et al., 2013; Sivakumar et al., 2014). Indeed, because of their long-lasting socioeconomic impacts, droughts are by far considered the most damaging of all natural disasters (Sivakumar et al., 2014). Over the United States, droughts cause $6–8 billion per year damages on average, but as much as 22 events between 1980 and 2014 resulted in over $200 billion costs (NCDC, 2015). Current estimates by the European Commission (CEC, 2007) indicate that the damages of droughts in Europe over the last 30 years are at least €100 billion. On top of that, the European Environmental Agency EEA (2010) reported that the annual average economic impact from droughts doubled between 1976–1990 and 1991–2006, rising to €6.2 billion per year in the most recent period. In India a drought has been reported at least once in every three years in the last five decades (Mishra et al., 2009; UNISDR, 2009a). Moreover, the country has suffered a financial loss of about $149 billion and 350 million people got affected due to droughts in the past 10 years (Gupta et al., 2011).

While large economic impacts of droughts are most relevant in wealthy industrialized nations, its social impacts are particularly severe in food-deficit countries with high dependence on subsistence agriculture and primary sector activities (Reed, 1997). In such cases, drought events combined with poor governance and poorly functioning market systems, oppressive policies, and intermittent or insufficient food aid, has historically lead to food insecurity, famine, human conflicts and widespread mortality (Below et al., 2007; Gráda, 2007). For example, severe droughts in the 1980s resulted in massive socioeconomic disruptions in the West African Sahel: pastures and water bodies were largely depleted, local populations suffered severe food shortages, and over half a million people were killed (Hulme, 1996; Kallis, 2008; Traore et al., 2014). In North Africa, four severe droughts between 2000 and 2011 brought 2–3 million people in extreme poverty and wiped out 80–85% of herd stock (UN-DESA, 2013). More recently, some analysts have argued that disasters related to drought, including agriculture failing, water shortages and water mismanagement have played an important role in contributing to the deterioration of social structures and spurring violence that began in Syria in March 2011 (Gleick, 2014; Kelley et al., 2015).

In order to reduce the global threat of drought, an increasing number of international initiatives, such as the "Hygo Framework for Action 2005–2015: Building resilience of Nations and Communities to Disaster" (UNISDR, 2009a,b) and the "High-level Meeting on National Drought Policy" (WMO, 2013), have begun to encourage all the governments around the world to move towards a drought-resilient society. Although providing a safety net for those people or sectors most vulnerable to drought is always a high priority, the challenge now is to do it in a manner that engenders cooperation and coordination between different levels of governance in order to reinforce the tenets of proactive drought risk reduction strategies (Kampragou et al., 2011; Sivakumar et al., 2014; Wilhite et al., 2014). This new paradigm emphasizes greater understanding of both the natural features of drought and the factors that influence social and economic vulnerability. In this context, progress on global drought risk management is particularly important. It addresses questions that are difficult (or currently impossible) for local management to address, namely those related to tightly interlocked global impacts that cause and/or exacerbate local economic and social vulnerability, such as increasing food prices and food insecurity (Dai, 2011; Pozzi et al., 2013; Wilhite et al., 2014). If food prices continue to increase, it will seriously compromise efforts to reduce vulnerability and regions with increasing food insecurity will be progressively less adapted to drought hazard (UNISDR, 2009b). Since international support on risk management to those most affected is based on prioritized adaptive needs, and regional cooperation funds to reinforce national adaptation plans are most reflected in decisions taken at the global level, then it is extremely important to identify the regions where drought impacts might be especially sensitive and development aid can be best concentrated (Alcamo and Henrichs, 2002; UNISDR, 2009b).

Despite current concerns about increasing drought impacts on food, water and energy sectors, several authors have warned that more global efforts are spent on studying and quantifying drought as a natural hazard than at providing a consistent and equitable drought risk management framework for multiple regions, population groups and economic sectors (Eriyagama et al., 2009; Kampragou et al., 2011; Shiau and Hsiao, 2012; Pulwarty and Sivakumar, 2014; Kim et al., 2015; González Tánago et al., 2015). In this paper we, therefore, provide practical insight into useful and freely available science-based resources for mapping the global patterns of drought risk. We concentrate on a data-driven approach that is based on the combination of independent indicators of historical drought hazard and current estimates of drought exposure and vulnerability, as previously suggested by Dao and Peduzzi (2003), Peduzzi et al. (2009) and Cardona et al. (2012). It is a kind of first screening analysis to determine where local assessments should be carried out to improve adaptation plans and mitigation activities, and strengthen multiscale drought risk management policies. Moreover, comparing risk across regions can identify leverage points in reducing impacts from drought and, by inference, from climate change, which is likely to be manifested through increases in the frequency of drought events at least in the short- to medium-term. The paper is organized as follows: this section begins by examining the underlying concepts of drought impacts, crisis and risk management; Section 2 gives an overview of drought risk and the proposed efforts for estimating its determinants; in the third section, the data used for mapping the global distribution of drought risk and its determinants are described, and the performance assessment to evaluate the robustness of the underlying models is outlined; after a discussion about the spatial distribution of risk and its determinants in Section 4, the study is concluded in Section 5.

## 2. Defining and mapping drought risk

Definitions of risk are commonly probabilistic in nature, referring to the potential losses from a particular hazard to a specified element at risk in a particular future time period (Blaikie et al., 1994; Brooks et al., 2005). Drought risk is the probability of harmful consequences or likelihood of losses resulting from interactions between drought hazard (i.e. the possible future occurrence of drought events), drought exposure (i.e. the total population, its livelihoods and assets in an area in which drought events may occur), and drought vulnerability (i.e. the propensity of exposed elements to suffer adverse effects when impacted by a