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Multi-dimensional assessment of drought vulnerability in Africa: 1960–2100

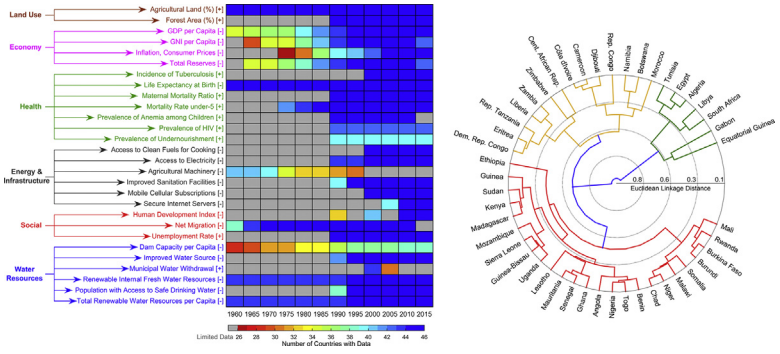
Ali Ahmadalipour *, Hamid Moradkhani

Center for Complex Hydrosystems Research, Department of Civil, Construction, and Environmental Engineering, University of Alabama, Tuscaloosa, AL 35487, USA

HIGHLIGHTS

- A comprehensive assessment is conducted to analyze drought vulnerability in Africa.
- Various socioeconomic datasets (28 factors from 6 major components) are utilized.
- Drought Vulnerability Index (DVI) is calculated at national scale during 1960–2015.
- The most and least vulnerable countries are identified over time.
- Following statistical analyses, DVI is projected for future period of 2020–2100.

GRAPHICAL ABSTRACT



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ABSTRACT

Drought vulnerability is a complex concept that identifies the capacity to cope with drought, and reveals the susceptibility of a system to the adverse impacts of drought. In this study, a multi-dimensional modeling framework is carried out to investigate drought vulnerability at a national level across the African continent. Data from 28 factors in six different components (i.e. economy, energy and infrastructure, health, land use, society, and water resources) are collected for 46 African countries during 1960–2015, and a composite Drought Vulnerability Index (DVI) is calculated for each country. Various analyses are conducted to assess the reliability and accuracy of the proposed DVI, and the index is evaluated against historical observed drought impacts. Then, regression models are fitted to the historical time-series of DVI for each country, and the models are extrapolated for the period of 2020–2100 to provide three future scenarios of DVI projection (low, medium, and high) based on historical variations and trends. Results show that Egypt, Tunisia, and Algeria are the least drought vulnerable countries, and Chad, Niger, and Malawi are the most drought vulnerable countries in Africa. Future DVI projections indicate that the difference between low- and high-vulnerable countries will increase in future, with most of the southern and northern African countries becoming less vulnerable to drought, whereas the majority of central African countries indicate increasing drought vulnerability. The projected DVIs can be utilized for long-term drought risk analysis as well as strategic adaptation planning purposes.

1. Introduction

Drought is a recurring natural hazard affecting large areas with severe impacts on the environment, society, and economy (Naumann et al., 2014). It imposes the most negative consequences in Africa

* Corresponding author.
E-mail addresses: aahmada@ua.edu (A. Ahmadalipour), hmoradkhani@ua.edu (H. Moradkhani).

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causing famine and land degradation (Lyon, 2014; Scrimshaw, 1987). Drought is among the costliest natural hazards due to slow onset, vast spatial extent, and prolonged duration (Ahmadalipour and Moradkhani, 2017; Yan et al., 2017). It stands out as the greatest natural hazard in Africa with a total of 382 reported drought events between 1960 and 2006 affecting 326 million people (Gautam, 2006; Shiferaw et al., 2014).

Vulnerability is defined as the level of susceptibility of a system to harm from exposure to stresses and hazards (Adger, 2006; Birkmann, 2007). It reflects the degree to which a system is unable to adapt to the adverse effects of a shock experienced (Füssel, 2007; Mohmmed et al., 2018). Vulnerability is usually constituted by components of exposure and sensitivity to perturbations and external stresses (Birkmann et al., 2013; Koutroulis et al., 2018; Parry et al., 2007). In other words, a natural disaster with the same level of hazard may impose different consequences in various regions due to the distinct underlying vulnerabilities (Vicente-Serrano et al., 2012).

Understanding drought vulnerability can improve the preparedness of a region, and hence reduces the devastating impacts of hazards by promoting drought mitigation at national and regional levels (Iglesias et al., 2007; Naumann et al., 2014). However, comprehending and quantifying vulnerability is a complex challenge as it depends on biophysical and socioeconomic factors, and requires expert knowledge (Mohmmed et al., 2018; Shiferaw et al., 2014). In particular, assessing drought vulnerability is of high complexity due to the intricate impacts of drought on various natural and social components. Furthermore, there is no consistent method for quantitative assessment of drought vulnerability (Vicente-Serrano et al., 2012). Therefore, it is necessary to incorporate different components that will be affected by drought including environment, health, society, and economy into vulnerability assessments (Smit et al., 1999).

Two of the worst natural disasters of the world in the past decades were the Ethiopia/Sudan drought of 1974 and the Sahel drought of 2007 causing 450,000 and 325,000 deaths, respectively (Vicente-Serrano et al., 2012). The 2010–2011 drought of the Greater Horn of Africa was the worst drought in the region for over 60 years, which affected over 12 million people (Checchi and Robinson, 2013; Tierney et al., 2013). It resulted in massive migration, extreme food shortages, and mortality of over 260,000 people (Loewenberg, 2011; Nicholson, 2014). Prolonged drought conditions impose the most significant climate impacts on gross domestic product (GDP) per capita growth in Africa (Brown et al., 2011).

Masih et al. (2014) performed a comprehensive review of droughts in Africa to understand the causes and impacts of historical drought events. They concluded that the African continent is expected to experience extreme and widespread droughts in future. It has been discussed that the vulnerability of communities and ecosystems to drought has generally increased in Africa over the past decades mainly due to over-exploitation of natural resources and population growth (Antwi-Agyei et al., 2012). Therefore, it is important to assess drought vulnerability using quantitative and objective frameworks in order to understand its historical variations across Africa.

A few studies assessed drought vulnerability in Africa for various geographical domains. Eriksen et al. (2005) conducted one of the first drought vulnerability assessments of Kenya and Tanzania based on few socio-economic and food insecurity factors. They identified vulnerability of households and adaptation strategies based on regional resources. Eriksen and O'Brien (2007) introduced a conceptual understanding of the relationship between vulnerability and poverty, and investigated how climate change adaptation can reduce poverty and vulnerability in Kenya. Schilling et al. (2012) studied the impacts of climate change on drought hazard in the Sahel region. They quantified vulnerability to drought mainly based on agricultural and economical sectors, and concluded that climate change will most likely impose the strongest impacts on Morocco's agricultural sector. Antwi-Agyei et al. (2012) carried out a regional drought vulnerability analysis based on the impacts of drought on crop yield in Ghana. Shiferaw et al. (2014) investigated drought vulnerability and impacts in Africa using agricultural yield and economic losses for the period of 2006–2012 and reviewed the ongoing drought risk management strategies. More recently, Naumann et al. (2014) quantified drought vulnerability across Africa according to four components of renewable natural capital, economic capacity, human and civic resources, and infrastructure and technology.

Regional drought vulnerability assessments are of high importance for local water resource management and drought preparedness. Studies have investigated drought vulnerability in Bangladesh (Shahid and Behrawan, 2008), China (Simelton et al., 2009), Morocco (Schilling et al., 2012), South Korea (Kim et al., 2015), and India (Singh and Kumar, 2015) for such purposes. Nonetheless, regional assessments are unable to reliably address the resilience and adaptive capacity from a comparative viewpoint. On the other hand, some of the studies have assessed vulnerability at global scale (Carrao et al., 2016; Fraser et al., 2013). However, comparing developed countries having abundant water resources (e.g. Sweden) and poorly developed countries with low access to freshwater (e.g. Chad) does not accurately capture the regional characteristics of vulnerability.

One of the primary shortcomings of many drought vulnerability assessments is their static formulation and investigation, which does not allow for diagnosing the variations of drought vulnerability over time. Furthermore, many studies solely focused on economical or agricultural factors of vulnerability and ignored other aspects such as health and social development. Considering the devastating impacts of drought in the least developed countries of Africa, it is essential to account for as many relevant factors as possible.

The present study provides a comprehensive assessment of drought vulnerability across the African continent based on a multi-dimensional analysis of several socio-economic components. Drought Vulnerability Index (DVI) is quantified and analyzed for each country during the historical period. DVI is then projected for the future period in order to provide a probable DVI for each country based on its long-term historical variations and trends. The study builds up on the previous drought vulnerability assessments and provides answers to the following research objectives:

- Identifying the dominant independent factors for quantifying drought vulnerability in Africa.
- Providing a reliable weighting method for probabilistic calculation of DVI from different factors.
- Assessing the historical changes of DVI for each country in Africa during 1960–2015 and projecting DVI for the period of 2020–2100.
- Detecting the most and least drought vulnerable countries in Africa, and analyzing their resilience over time.

The paper is organized as follows: data and methodology are explained in the next sections, followed by results and discussion, and the findings are summarized at the end.

2. Data

The first step for quantifying drought vulnerability is to identify the relevant factors that address different dimensions of drought impacts including environment, health, society, and economy (Smit et al., 1999). Since the impacts of drought on natural and human resources are distinct for different regions, it is not possible to define a uniform measure of drought vulnerability suitable for everywhere. Therefore, selecting relevant factors requires expert knowledge about the study region.

In this study, vulnerability factors are divided into six main categories (components) including economy, energy and infrastructure, health, land use, social, and water resources. Different data sources