A global picture of drought occurrence, magnitude and preparedness

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A global picture of drought occurrence, magnitude and preparedness

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Abstract. This study examines the global patterns and impacts of droughts through the mapping of several drought-related characteristics – either at a grid or a country scale. Characteristics cover various aspects of droughts from global distribution of meteorological and hydrological drought risks to social vulnerability and indices related to water infrastructure. The maps are produced by integrating a number of publicly available global datasets. The subsequent discussion of maps allows a number of policy relevant messages to be extracted. It appears that arid and semi-arid areas also tend to have a higher probability of drought occurrence. In drought years, the highest per capita loss of river flow occurs in areas that do not normally experience climate-driven water scarcity. The study illustrates that the African continent is lagging behind the rest of the world on many indicators related to drought preparedness and that agricultural economies, overall, are much more vulnerable to adverse societal impacts of meteorological droughts. Also highlighted are regions having the largest drought deficits and durations. The ability of various countries to satisfy their water needs during drought conditions is examined using storage-related indices.

Keywords. Drought – Indicators – Mapping – Climate change – Natural disasters.

Cartographie mondiale des sécheresses : Fréquence, magnitude, et prédispositions des pays

Résumé. *Cette étude examine la répartition spatiale des sécheresses et de leurs impacts à l'échelle mondiale, via l'établissement de cartes étatiques ou maillées. Ces cartes, résultant de l'intégration de jeux de données de niveau mondial, en libre accès, traduisent différents aspects physiques et socio-économiques des sécheresses : distribution des risques de sécheresse météorologique et hydrologique, vulnérabilité des populations, indices liés à la présence d'infrastructures hydrauliques. Plusieurs messages, utiles aux décideurs, émanent de cette analyse cartographique. Les régions arides et semi-arides sont particulièrement exposées aux risques de sécheresse. En années sèches, les réductions de débit des cours d'eau, rapportées au nombre d'habitants concernés, sont maximales dans les zones qui ne sont habituellement pas affectées par les pénuries d'eau d'origine météorologique. Avec des économies agricoles figurant parmi les plus vulnérables, le continent africain est le moins bien prémuni contre les risques de sécheresse. Cette étude identifie les régions présentant les déficits hydriques les plus marqués en termes d'intensité et de durée. La capacité de différents pays à satisfaire leurs besoins en eau pendant les périodes de sécheresse est évaluée à partir d'indices de stockage.*

Mots-clés. *Sécheresse – Indices – Cartographie – Changement climatique – Catastrophes naturelles.*

I – Introduction

Droughts can be generally defined as a temporary meteorological event, which stems from a deficiency of precipitation over an extended period of time compared to some long-term average conditions. It is one of the most complex natural phenomena that continue to have significant impacts in both developed and developing countries. With the ever increasing exploitation of water resources and associated water scarcity, coupled with the growing concern that future climate change will exacerbate the frequency, severity and duration of drought events, individual countries are paying increasing attention to drought related issues (Wilhite, 2005). It is useful from a global development perspective, to understand the pattern of various drought-related characteristics and impacts worldwide. Such characteristics should reflect multiple aspects of drought, ranging from quantification of drought hazard and vulnerability of water resources systems to measures of preparedness to face future droughts. One good way of presenting diverse materials related to droughts is through mapping, whereby various drought-related indicators can be plotted at a country resolution, river basin or a regular grid – depending on the type of indicator and information available. Review of past literature suggest that while the research and mapping of disaster risks, water scarcity, climate change and related subjects has been significant, there has been little, if any, attempt to date to comprehensively describe and map various aspects and impacts of drought as an individual natural disaster and a global multi-faceted phenomenon. The aim of this study is, therefore, to start filling this niche by designing and analysing a limited set of drought-relevant global maps.

II – Datasets drought characteristics and indices

The study used a number of publicly available datasets ranging from demographics and socioeconomics to natural resources and climate. Some of the indices mapped are drought related indices, which were either used locally rather than globally, or used out of the context with drought studies. Some others are existing indices, which although designed for a different purpose originally, carry useful drought related information, if used either as is or with certain modifications. A few have been newly formulated. This section provides a brief description of some of the indices and characteristics including computation method, scale, data sources and source of original indicator. However, only a select set of maps are presented here due to space restrictions.

Long-term *Mean Annual Precipitation (MAP)*, its *Coefficient of Variation (CV)* and *Probability (%) of annual precipitation in any year being less than 75% of its long-term mean* (Fig. 1) were mapped at a $0.5° \times 0.5°$ grid cell resolution. The University of East Anglia CRU TS 2.0 dataset (www.cru.uea.ac.uk/cru/data/hrg/timm/grid/CRU_TS_2_0.html) was used for calculating the indices.

The *Socioeconomic Drought Vulnerability Index* (Fig. 2) is a measure of each country's dependence on agriculture for their income and employment generation. It is similar to UNDP's Human Development Index (UNDP, 2006), in which the values of each component indicator are normalized to the range of values in the country dataset. The index ranges from 0-100 with 100 implying higher dependence on agriculture. It was calculated as:

$$SDI = 0.4IDI + 0.4EDI + 0.2CDI$$

where IDI = Income Diversity Index (proxy: percentage contribution from agriculture to national GDP); EDI = Employment Diversity Index [proxy: percentage employed in agriculture (% of total employment)]; CDI = Crop Range Index [proxy: Crops Diversity Index by Jülich (2006)]. The index was mapped at country scale using data from FAO's ProdSTAT database (http://faostat.fao.org/site/339/default.aspx) and World Bank's WDI online database (www.worldbank.org/).

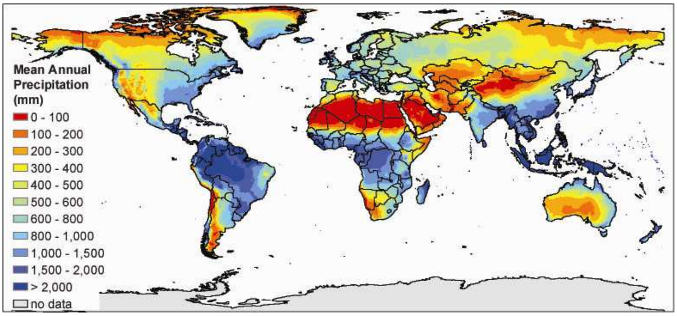
The *Infrastructure Vulnerability Index* (map not shown here) is a similar indicator measuring the level of development of the road network and water supply by country (modified and simplified to suit drought vulnerability from O'Brien *et al.*, 2004).

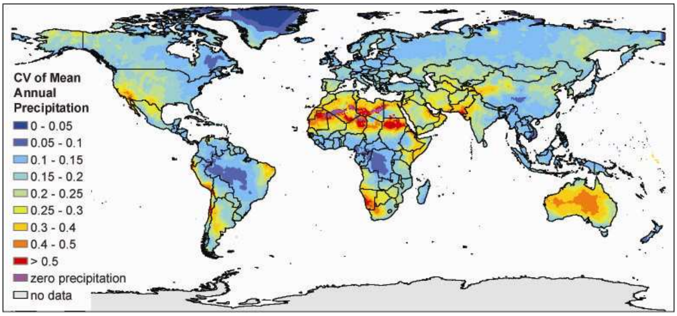
Two storage related indices were newly formulated and mapped in this study. They are: the *Storage-Drought Duration (Length) Index (SLI)* and the *Storage-Drought Deficit Index (SDI)* (Fig. 3). The SLI is the fraction of the annual drought duration in a country (how long a country is in drought in any given year) that its present storage capacity is able to satisfy, based on its monthly surface water demand. The SDI is how much of the annual hydrological drought deficit relative to long-term mean monthly river discharge is satisfied by the existing storage capacity in a country. They were calculated as:

$$SLI = \frac{SC/SW}{DDM}\ ;\ SDI = \frac{SC}{MAD}$$

where: SC = Storage capacity; SW = Monthly surface water withdrawals; DDM = Annual hydrological drought duration (months); and MAD = Annual hydrological drought deficit relative to long- term mean monthly river discharge. The main data sources for mapping these indices were: ICOLD World Register of Dams (1998) (www.icold-cigb.net/); AQUASTAT (FAO) (faostat.fao.org/site/544/default.aspx); University of New Hampshire WWDRII (wwdrii.sr.unh.edu) and river discharge time series grids (www.grdc.sr.unh.edu/index.html).

Other indices mapped include, *Per Capita Mean Annual River Discharge* (not shown here), two *Agricultural Water Crowding Indices* (Sullivan *et al.*, 2006) (not shown here), two *Drought Risk Indices* (Hashimoto *et al.*, 1982; McMahon *et al.*, 2006) (Fig. 4) and *Mean River Discharge Drought Run Duration* (not shown here), using publicly available datasets such as the CIESIN GPWv3 (sedac.ciesin.columbia.edu/gpw/).





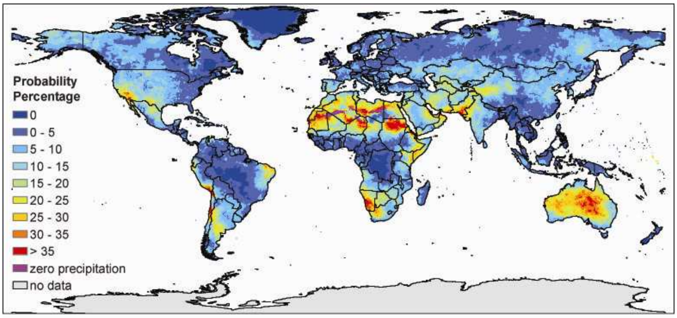


Fig. 1. Global distribution of Mean Annual Precipitation (top), its Coefficient of Variation (centre) and Probability % of annual precipitation in any year being less than 75% of its long-term mean.

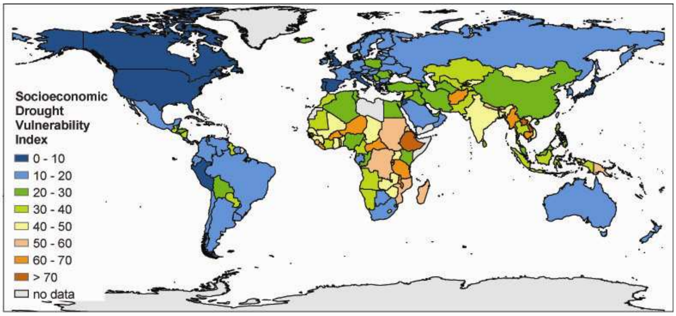


Fig. 2. Socioeconomic Drought Vulnerability Index based on crop diversity of individual countries and their dependence on agriculture for income and employment generation.

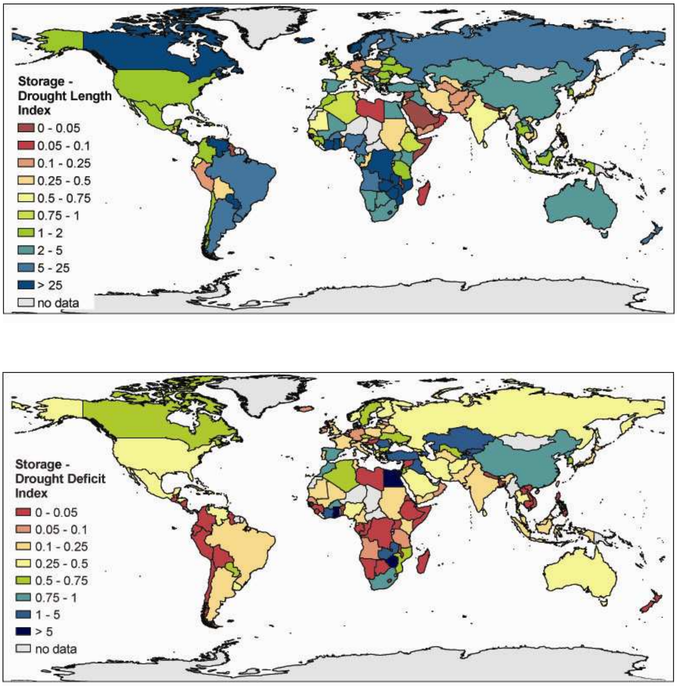
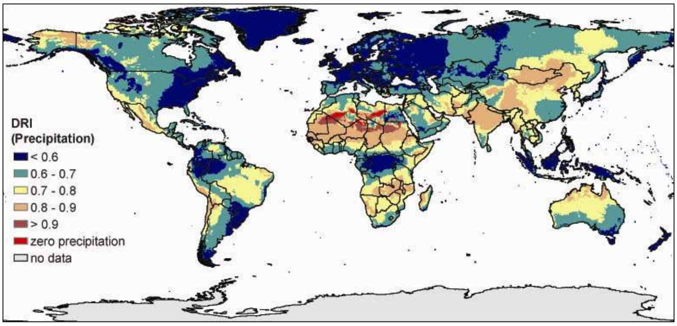


Fig. 3. Storage-Drought Duration (Length) Index (top) and Storage-Drought Deficit Index (bottom).

III – Results and discussion

The maps presented in Fig. 1 effectively describe the natural availability of water resources in any specific region. It appears, that areas which are naturally arid or semi-arid (e.g., receiving less rainfall over the long-term) also tend to have higher CV of mean annual precipitation and, consequently, higher probability of drought occurrence (regarded here as MAP being less the

75% of its long-term mean, Fig. 1). *Socioeconomic drought vulnerability* (Fig. 2) is generally higher throughout Africa and Asia since many African and Asian countries are largely agricultural economies. In contrast, North, and South America, Australia and Europe display much lower socioeconomic drought vulnerability. The more complex economies of developed countries insolate the population to fluctuations in agricultural productivity due to drought.



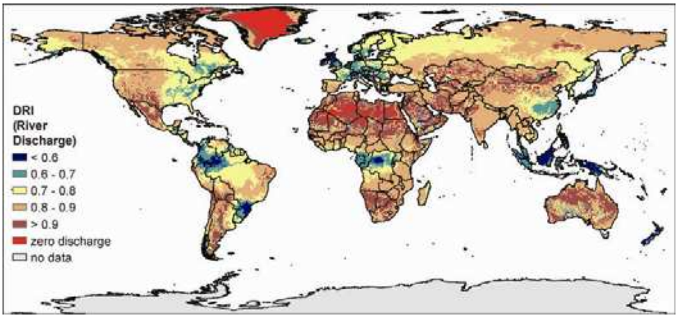


Fig. 4. Drought Risk Index (0-1) with respect to monthly precipitation (top) and monthly river discharge (bottom) based on the frequency of precipitation/river discharge drought occurrence and drought intensity (deficit below long term mean). Brown areas have higher drought risk.

Figure 3 illustrates that the *river discharge Drought Risk Index* is higher than the *precipitation Drought Risk Index* throughout the world, except for a few pockets in South America, Africa and Southeast Asia, highlighting the unreliable and vulnerable nature of river discharge over precipitation. In general, the arid and semi-arid areas have a higher drought risk index than the rest of the world, implying frequent drought occurrence and higher drought intensity when drought does occur. Europe is "better-off" in terms of this index and Africa is the worst case. Out of all areas having comparatively longer drought run durations, southern Africa, Australia, most of South and Central America and the United States seem to be able to satisfy their water needs, throughout the annual hydrological (river discharge) drought duration [*Storage-Drought Duration (Length) Index* >= 1], with the current storage facilities, unlike some countries in Central and South Asia, where this index is lower than 0.5 (Fig. 4 top). The worst cases include Saudi Arabia, Oman, Madagascar, Somalia, Kuwait, Syria, Slovakia, Hungary and Nepal. An analysis of present storage capacity as a percentage of total available annual freshwater resources (not mapped here), reveals that many of the countries which score low on this index, (especially those in Asia) have no apparent hydrological barriers for increasing storage in the future except perhaps Libya which is already storing 0.5-0.75 of its annual freshwater resources. Only a few countries score high on the *Storage-Drought Deficit Index* (Fig. 4 bottom). They are Egypt, Morocco, Ghana, Ivory Coast, Burkina Faso, Zambia, Malawi, Zimbabwe, Burundi, South Africa, China, Uzbekistan, Kyrgyzstan, Tajikistan, Iraq, Turkey, Azerbaijan, Romania and Spain. They also "perform satisfactorily" on both storage indices, while having the highest ratios of storage to total annual renewable freshwater resources. A closer analysis of both maps suggest that those countries which score high on the *Storage-Drought Duration (Length) Index* can be reasonably assumed to possess satisfactory storage to meet their freshwater demands during drought. On the other hand, those countries which score high on both indices are also often the ones which are more susceptible to river fragmentation and over-exploitation of freshwater resources (e.g., China, Egypt, South Africa) (Revenga *et al.*, 2000).

Other messages arising out of the study (including from maps not shown here) indicate that in drought years, the highest per capita water losses occur not so much in the driest regions, but rather in regions which are not normally water scarce due to climate. The *Agricultural Water Crowding Indices* indicate that there might be potential for rainwater use in agriculture which could be tapped with increased rainwater harvesting as frequently called for by other studies (Comprehensive Assessment of Water Management in Agriculture, 2007; Falkenmark *et al.*, 2007). It is also evident that the African continent is lagging behind the rest of the world on many indicators related to drought preparedness. A large part of Africa, South, Southwest and Central Asia and northern Australia (all arid and semi-arid regions) are more prone to multi-year hydrological droughts. However, major parts of South and North America and most of Europe appear to be less prone to multi-year droughts.

IV – Conclusions

This study reviewed all the previous known attempts to approach the issue of drought analysis at the global scale. The review highlighted the absence of global scale studies that comprehensively describe and map various aspects and impacts of drought as an individual natural disaster. Hence this study aimed to start filling this niche by producing a set of global maps of various drought-related characteristics, integrating a number of publicly available global datasets. It is hoped that this limited set of maps may, with subsequent contributions from other research groups, develop into a comprehensive global drought indicators' "atlas" in the future, while feeding into operational drought tools (drought monitoring, drought early warning systems, etc.) and national drought preparedness plans. At the same time, it is important to note that this study gives a rather general "global" illustration of various drought-related factors, and should not be used to make sweeping generalizations at the local scale.

Future drought research should also examine the differences in impacts and response options between short-term and long-term droughts more closely. Quantifying and indexing vulnerability to droughts within countries and at local and household levels, to identify vulnerable groups and populations represents another challenge and research niche. It will also be of interest to identify how some of the mapped indices in this study might alter with climate change.

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