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A probabilistic approach to assess agricultural drought risk to maize in Southern Africa and millet in Western Sahel using satellite estimated rainfall

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ABSTRACT

Mainstreaming disaster risk reduction is a novel perspective of managing natural hazards. Risk analysis consists of four basic analytical modules – hazard, exposure, vulnerability and risk to determine risk metrics. Risk metrics are losses corresponding to different return periods and their likelihood derived from stochastic evaluations of historical and simulated loss data – this process is called risk profiling for a given natural hazard in a given region. The U.S. Agency for International Development (USAID) funded Famine Early Warning Systems Network (FEWS NET) has been monitoring food security issues in the sub-Saharan Africa, Asia, and Central America and in Haiti. FEWS NET uses satellite based rainfall and climatic water demands to monitor moisture availability conditions for deriving food security status in Africa. This paper highlights the results of agricultural drought risk profiling analyses for maize in Malawi and Mozambique in Southern Africa, and for millet in Niger in West Sahel. Historical maize and millet yields have been analyzed to develop drought vulnerability models using the satellite rainfall based-water requirement satisfaction index (WRSI) in the above countries. In view of the limited hazard and exposure data (2000 to present) long-term synthetic rainfall time series were generated. The loss exceedance probability (LEP) curves, return period losses and drought frequency maps indicating district-level drought-proneness for the target crops in the selected countries have been generated.

1. Introduction

The classical approach of drought analysis consists of characterization from meteorological, hydrological, or agricultural points of view. These characterizations imply a certain temporal component in their analysis. For example, a meteorological drought at a given location is commonly defined using quantiles based on rainfall data for short periods of a few days to a month. Likewise, the hydrological droughts are characterized by events ranging from months to years that impact hydrological variables like reservoir storage, river flow, and soil moisture depending on the location. However, in the case of agriculture drought, the practice to date has been to use meteorological drought characterization in the interpretation of associated reductions in crop vigor

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and yields. Currently, a novel approach of mainstreaming of disaster risk reduction is being adopted in the field of agricultural drought analysis. This new approach involves stochastic analysis of the spatio-temporal vulnerability of crops to quantify the frequency of events impacting crop production. Stochastic analysis of natural hazards in general and droughts in particular, is the basic paradigm of mainstreaming drought risk reduction [2]. Event-likelihoods corresponding to different magnitudes of crop production losses caused by historical and simulated droughts are used to profile the agricultural drought characteristics of a region.

The core of the mainstreaming drought risk management philosophy consists of four analytical components – hazard, exposure, vulnerability, and risk [2]. Drought as a natural hazard results from abnormally deficient rainfall in a given region. This has a cascading effect on surface and subsurface water storage, stream and river flows, lower soil water moisture for agricultural areas and pastures, and reduced water availability for both human and livestock consumption. Drought hazard analysis consists of selecting an appropriate hydro-meteorological index to describe its intensity, spatial and temporal characteristics. Long-term rainfall records and ancillary hydrologic data inform relevant hazard indices to depict drought characteristics in a given region.

Drought hazard indices in the past have been constructed using deficiencies in rainfall averaged over periods ranging from fortnights, months, to several years or even decades depending on the drought characteristics of the region [13]. In 2009, the World Meteorological Organization (WMO) recommended the use of the Standardized Precipitation Index (SPI) [20] as the global standard hazard index to measure droughts via the 'Lincoln Declaration on Drought Indices' [17]. The SPI is computationally easy and facilitates transferability across temporal and spatial scales. The main difficulty in using the SPI is that it needs long-term rainfall data (at least 30 years of error-free data) to establish distribution parameters that represent the meteorological droughts in a given region. The SPI, in view of its computational ease, has also been used as an agricultural drought indicator (e.g. for irrigated rice in Philippines,[1] and rainfed maize in Malawi and Mozambique[2]). The inherent drawback in using the SPI, as an agricultural drought hazard index, lies in its presumption of a direct consequence of crop production losses in a given region and that it does not account for the role played by the soil in regulating moisture in the crop root zone.

The most relevant agricultural drought hazard index capturing crop vulnerability to drought is the gap between the crop water demand and the water available in its root zone, especially for rain fed crops. The variables that influence the corresponding crop losses include climatic water demand, soil fertility, water holding capacities, and crop characteristics (type, variety, drought susceptibility, etc.) and their management. These variables can be used to model the seasonal changes in the root zone soil water balance to derive the net antecedent conditions that affect the crop and its productivity potential at different phenological growth stages. These soil moisture availability hazard indices can be used to interpret both the spatial as well as the year-to-year crop yield variability in a given region.

The exposure component of mainstreaming identifies the facet of society, and the associated value, that is affected by the hazard. Exposure in the context of earthquakes consists of buildings (both residential and commercial), infrastructure damaged, and population affected. In the context of floods, exposure refers to low-lying infrastructure such as bridges, roads, buildings and crop areas along with the corresponding affected population. Exposure analysis in the context of agricultural droughts consists of historical crop area and production statistics in a given region. At least 20–30 years of continuous exposure data is needed to conduct objective probabilistic drought risk analysis.[1,2]

Vulnerability analysis captures the damage or loss suffered at the intersection of exposure and a hazard event, or the resiliency to exposure. It is related to the capacity of the exposed asset to predict, withstand, and recover from the deleterious effects of the hazard. Drought vulnerability analysis establishes the cause–effect relationship between the drought hazard and the exposure variables. This may be deduced either by crop process models using high resolution, high frequency agro-hydro-meteorological field data; or estimated using statistical relationships between drought hazard and the historical crop production losses.

The risk component quantifies the damage caused by the hazard in physical and monetary loss terms. The risk is expressed in two ways – graphic and numeric. The *loss exceedance probability* (LEP) curve is a graphical portrayal of the likelihood of specific physical or monetary losses. Numeric loss data is tabulated as the probabilities associated with exceeding discrete levels of loss, referred to as the *return period* losses.

The United Nations International Strategy for Disaster Reduction (UNISDR) publishes a Global Assessment Report (GAR) addressing all types of disaster risk reduction, including drought. The global standards for assessing drought hazard are currently being established [13]. In some of the most drought vulnerable areas of the world there are significant difficulties in getting data to develop risk models, especially from the famine and drought affected countries in Africa. The GAR 2011 report also highlighted that in the absence of a credible drought risk model, there is a need to understand agricultural drought impacts and losses using appropriate soil moisture based drought hazard indices. The UNISDR and the Famine Early Warning Systems Network (FEWS NET) have initiated a collaborative study to identify, develop and validate a probabilistic agricultural drought risk methodology using satellite estimated rainfall-based hazard indices that FEWS NET operationally uses to monitor food insecurity in Africa.

The probabilistic approach of drought risk assessment in this study consists of conducting a frequency analysis of the gaps between water demand and availability in the crop root zone during the crop season, constructing appropriate drought vulnerability models, and deriving loss exceedance

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[2] Economic vulnerability and disaster risk assessment in Malawi and Mozambique. RMSI report submitted to the World Bank. ⟨http://www.preventionweb.net/files/15520_gfdrrecon.vulnerabilitydrrmalawimoz.pdf⟩; November 2009.