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Abstract

Drought information systems have multiple sub-systems which include an integrated risk assessment, communication and decision support system of which early warning is a central component and output. There are numerous drought systems warning systems being implemented at different scales of governance from the international to the community. An early warning system is much more than a forecast-it is a linked risk information (including peoples' perception of risk) and communication system that actively engages communities involved in preparedness. The successes illustrate that effective early warning depends upon a multi-sectoral and interdisciplinary collaboration among all concerned actors at each stage in the warning process from monitoring to response and evaluation. However, the links between the community-based approach and the national and global EWSs are relatively weak. The paper identifies pathways for knowledge management and action at the relevant scales for decision-making.

Introduction

Drought has long been recognized as falling into the category of incremental but long-term and cumulative environmental changes, also termed slow-onset or creeping events. Similar issues include: soil degradation and desertification processes, ecosystems change and habitat fragmentation, nitrogen overloading, and coastal erosion, among others. Such creeping changes are often left unattended in their early stages since policymakers choose or need to cope with immediate crises. Eventually, neglected creeping changes may become urgent crises that are more costly to deal with since critical thresholds for reversibility have been exceeded (Glantz 2004). Early Warning Systems (EWS) in such contexts are needed not only for the event onset at which a threshold is exceeded, but also for intensification and duration ranging temporally from a single season to decades, and spatially from a few hundred to hundreds of thousands of square kilometers.

All dimensions of food, water, and natural capital security are affected by climate extremes and variability and are likely to be affected by climate change (IPCC, 2007). While climate change is commonly presented as a gradual shift in climatic trends, its impacts will be most strongly felt by resource insecure populations through changes in the distribution, nature and magnitude of extreme events as these affect crops, disease outbreaks, and soil and water quality.

The United Nations International Strategy for Disaster Reduction (UNISDR, 2006) notes that early warning information systems must be people-and placed centered, integrating four elements - (i) knowledge of the risks faced; (ii) technical monitoring and warning service; (iii) dissemination of meaningful warnings to those at risk; and (iv) public awareness and preparedness to act. The authors of the survey go on to argue that failure in any one of these elements can mean failure of the whole early warning system. Although recent drought-related disasters have contributed to a sense of urgency, drought has not received commensurate attention within natural hazards research as have the direct impacts of hurricanes and floods. Most countries, regions, and communities, currently manage drought risk through reactive, crisis-driven approaches (Wilhite et al. 2006).

In the following discussion a drought information system represents an integrated risk assessment, communication and decision support system of which early warning is a central component and output. In turn an early warning system much more than a forecast, it is a linked risk information and communication system that informs preparedness.

Drought Monitoring, Prediction, and Indicators

Drought is among the most damaging and least understood of all such hazards. Although some droughts last a single season and affect only small areas, the instrumental and paleoclimate record shows that droughts have sometimes continued for decades and have impacted millions of square kilometres in North America, West Africa, and East Asia. In 1991-1992, parts of Africa suffered the worst dry-spell of the twentieth century when drought covered a region of 6.7 million square kilometers and affected 24 million people. So memorable were the impacts of major drought events in regions such as the U.S. Great Plains, Sub-Saharan Africa, and the Nordeste in Brazil that they are embedded in literature and cultural memory. The combination of the above factors results in warning systems for drought being more complex than those for other hydrometeorological hazards and are, consequently, relatively less developed globally.

NOAA's National Weather Service (NWS) defines a drought as "a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area." Although all types of droughts (meteorological, hydrological, agricultural, and socio-economic) are initiated by an extended precipitation deficiency, it is insufficient solely to monitor this parameter to assess severity and resultant impacts. Effective drought monitoring systems integrate precipitation frequency and intensity and other climatic parameters with water information such as streamflow, snow pack, groundwater levels, reservoir and lake levels, and soil moisture into a comprehensive assessment of current and future drought and water supply conditions (Svoboda et al. 2002).

There have been significant scientific advances in the last two decades in climate prediction from 1 to 6 months in advance to help decision-makers reduce risks associated with climate variability (Pulwarty 2007). General Circulation Models (GCMs) and associated statistical ensemble methods are being routinely used to provide predictions of impending climate anomalies and offer promise for increasingly useful forecasts of the onset, severity and duration of drought for large geographic regions on monthly and seasonal timescales (Dai, 2010). Global aridity has increased substantially since the 1970s due to recent drying over Africa, southern Europe, East and South Asia, and eastern Australia. Although El Niño-Southern Oscillation (ENSO), tropical Atlantic SSTs, and Asian monsoons have played a large role in the recent drying, recent warming has increased atmospheric moisture demand and likely altered atmospheric circulation patterns, both contributing to drying.

Temperature and land surface feedback on drought intensification and how these affect components of the water budgets to estimate soil moisture (for agricultural drought monitoring), snowmelt runoff and discharge and groundwater-surface water interaction (for hydrological drought monitoring), and precipitation anomalies (for meteorological drought monitoring). These indicators are used to produce composite products based on other climate indices, numerical models and input of regional and local expert judgment. The classification schemes used for each indicator, and their relative limits and strengths are available from numerous sources (Heim, 2002; Dai, 2010). A comprehensive list of such indicators, such as the Standard Precipitation and Palmer Drought Severity Indices, is available on the NOAA (www.drought.gov) and NDMC (drought.unl.edu) webpages. Additional indicators may include the Palmer Crop Moisture Index, Keetch-Byram Drought Index, Fire Danger Index, and evaporation-related indicators such as relative humidity, temperature departures from normal, reservoir and lake levels, groundwater levels, surface soil moisture observations and snowpack. Some indicators are calculated at point locations and others at regional or climate divisions, drainage/hydrological basins, or other geographical units.

Change detection is critical in natural resources management (Ludwig et al. 1993). Due to the complex nature of droughts, a comprehensive and integrated approach that would consider numerous drought indicators is required for drought monitoring and early warning. Location-specific environmental changes (i.e. ecosystems changes, loss of biodiversity and habitats, land cover/land changes, coastal erosion, urban growth, etc.) become critical. Since 1972, Landsat satellite data have been extensively used for environmental changes providing multiple, synoptic, global coverage of high-resolution having multi-spectral imagery allowing for change detection over time. Drought monitoring thus requires a comprehensive and integrated approach to determine the drought extent and impacts. Central to detection is the characterization, monitoring, and understanding of land cover and land use change, since they have a major impact on sustainable land use, as well as land-atmosphere interactions affecting regional climate change (IGOS-P, 2004).

We now turn to a summary assessment of existing drought information systems in which the above indicators are used. The list is not meant to be comprehensive but illustrative of major ongoing activities.

International and National Drought Early Warning Systems: A Brief Survey

Over 10 years ago, an expert group meeting sponsored by the World Meteorological Organization (WMO) and others, documented the status of drought EWSs in several countries, the shortcomings and needs of drought EWSs, and recommendations on how these systems can help in achieving a greater level of drought preparedness (Wilhite et al. 2000). Risk assessment for early warning and risk management requires indicators that are internationally agreed and locally referenced. The WMO provides global meteorological information, such as precipitation levels, cloudiness, and weather forecasts. The FAO's Global Information and Early Warning System on Food and Agriculture (GIEWS) and Humanitarian Early Warning Service (HEWS) by the World Food Programme (WFP) provide information on major droughts occurring globally. The FAO-GIEWS provides information on countries facing food insecurity through monthly briefing reports on crop and food prospects, including drought information, together with an interactive map of countries in crisis. Reports are not specifically focused on drought conditions and are released monthly or less frequently. The HEWS collects drought status information from several sources including FAO-GIEWS, WFP, and Famine Early Warning System (FEWS Net), and synthesizes this information into maps and supporting notes (from FAO-GIEWS) which is then provided, on a monthly basis, through the HEWS website (UNEP, 2006). On a regional scale, the FEWS Net for Eastern Africa, Afghanistan, and Central America reports on current famine conditions including droughts, by providing monthly bulletins that are accessible on the FEWS Net webpage. Other efforts such as the Benfield Hazard Research Center of the University College London) produce global maps of monthly precipitation deficits.

Efforts in drought early warning in continue in countries such as Brazil, China, Hungary, India, Nigeria, South Africa, and the United States. Regional drought monitoring activities exist or are also being developed in eastern and southern Africa and efforts in West Asia and North Africa. The Southeast Asia Drought Monitor developed by the International Water Management Institute (IWMI), covers western India, Afghanistan and Pakistan. There is in general heavy reliance on remote sensing data and as such there are long-standing needs to improve in situ information such as meteorological and agricultural data.

The European Commission Joint Research Center (EC-JRC) provides publicly available drought-relevant information through the following real-time online maps: daily soil moisture maps of Europe; daily soil moisture anomaly maps of Europe; and daily maps of the forecasted top soil moisture development in Europe (7-day trend).

Regional Climate Outlook Fora comprising national, regional and international experts review conditions and develop climate outlooks primarily based on ENSO forecasts and teleconnections (WMO RCOFS). As an ENSO conditions develop in a particular year, the WMO coordinates the development of a global scientific consensus, involving a collaborative process to review best available evidences and predictions. The outcome is the El Niño Update, a unified global statement on the expected evolution of ENSO for months ahead, which is issued to NMHSs and to the world at large.

Many countries have developed drought early warning systems capable of integrating information from various sources and providing warnings of the imminent onset of drought. In Africa, regional centers such as the IGAD Climate Prediction and Applications Centre (ICPAC) and the Drought Monitoring Centre (DMC) in Harare, supported by WMO and regional economic commissions and the Sahara and Sahelian Observatory provide current data, develop climate outlooks and issue warnings to NMHSs.

At the national level for China, the Beijing Climate Center (BCC) of the China Meteorological Administration (CMA) monitors drought development. Based on precipitation and soil moisture monitoring from an agricultural meteorological station network and remote-sensing-based monitoring from CMA's National Satellite Meteorological Center, a drought report and a map on current drought conditions are produced daily and made available on their website. In Vietnam, drought forecasting and early warning is the responsibility of the "Short-term and Long-term Drought Forecasting Department", within the National Institute of Hydro-meteorology. At the state level in India, the drought management system follows a uniform approach throughout the country, though few exceptions exist (Prabhakar and Shaw 2007). The states have established a drought early warning system, under the Weather Watch Group. The Karnataka state has established a special Drought Monitoring Center. The center monitors rainfall, water-reservoir levels and other relevant parameters on daily basis in the rainy season improving the capacity of states in terms of analyzing the weather information (Prabhakar and Shaw 2007).

In the United States the National Integrated Drought Information System (NIDIS) and the National Drought mitigation Center (NDMC) supports or conducts impacts assessment, forecast improvements, indicators and management triggers and the development of watershed scale information portals (web-based). In partnership with other agencies, tribes and states, the NIDIS teams coordinate and develop capacity to prototype and then implement regional drought early warning information systems using the information portals and other sources of local drought knowledge. The U.S. Drought Monitor, an innovative partnership among academia and Federal agencies (Svoboda et al. 2002), provides drought current conditions at the national and state level through an interactive map available on the website accompanied with a narrative on current drought impacts and a brief description of forecasts for the following week. It has a unique approach that integrates multiple drought indicators with field information and expert input, and provides information through a single easy-to-read map of current drought conditions and notes on drought forecast conditions across the nation. The U.S. Monitor and its offspring, the North American Drought Monitor, form a basis for NIDIS and other early warning systems (Svoboda et al. 2002).

Major parts of the world which face recurring severe droughts, still do not have comprehensive information and early warning systems in place (such as in western and southern Africa, eastern China, parts of India, South America, and the Mediterranean Basin, among others).

Some innovative approaches to creating integrated indicators from available climate and socio-economic datasets are being undertaken. Global patterns and impacts of droughts through the mapping of several drought-related characteristics – either at a country level or at regular grid scales. The maps are produced by integrating a number of publicly available global datasets (Eriyagam et al. 2009). Other relevant mapping projects are carried out primarily by a few international organizations/ projects, although they are not normally focusing on droughts per se. UNEP's World Atlas of Desertification shows the global extent and severity of desertification (Middleton 1997; UNEP1992).

In some areas, farmers have identified local language radio programs as credible and accessible mechanisms to deliver forecasts if they occur with follow up meetings with extension agents or other intermediaries (Pulwarty 2007). This latter point of following-up is non-trivial. Traditional forecasting remains an important source of climate information in many rural communities. There is growing appreciation that traditional observations and outlook methods may have scientific validity and increased interest in harmonizing traditional and modern scientific methods of climate prediction. Studies have been initiated in some countries, such as Zimbabwe and Kenya, to gain further understanding of traditional forecasting.

For most locations early warning is still treated as a linear process. There are multiple factors that limit current drought EWS capabilities and the application of data in drought preparedness, mitigation, and response globally (Wilhite et al. 2000). These include: inadequate density and data quality of meteorological and hydrological data and the lack of data networks on all major climate and water supply parameters; data sharing – inadequate data sharing between government agencies and the high cost of data limits, inadequate indices for detecting the early onset and end of drought although the Standardized Precipitation Index (SPI) has been cited as an important monitoring tool. Other issues of concern, the lack of specificity of information provided by forecasts, especially during non-ENSO years, limit the use of this information by farmers and others, and the fact that early warning system data and information products are often not user accessible and users are often not trained in the application of this information to decision making (Pulwarty 2007).

Reframing Early Warning: From Forecasts to Information Systems in Support of Adaptation

Adaptive actions are adjustments in assets, livelihoods, behaviors, technologies, and polices that address ongoing and future climates variability and change (IPCC 2011). Drought information systems are an important tool in a government's and community's portfolio to achieve adaptation as an output of sustainable practices. Drought early warning triggers multiple other warnings systems (such as for water resources, wildfire, etc) in a cascade of "early warnings" (Glantz 2004). The above examples illustrate that effective early warning depends upon a multi-sectoral and interdisciplinary collaboration among all concerned actors at each stage in the warning process from monitoring to responding (Glantz 2004; Pulwarty and Verdin 2011). However, the links between the community-based approach and the national and global EWSs are relatively weak (Birkmann et al. 2011, Pulwarty and Verdin 2011). Monnik (2000) noted, some years, ago that the main constraints on implementation include:

- Lack of a national and regional drought policy framework,
- Lack of coordination between institutions that provide different types of drought early warning, and the
- Lack of social indicators to form part of a comprehensive early warning system

Some reasons for this situation include the complexity of decision making processes; the diversity of responses across regions; monitoring gaps and uncertainty about climate changes at local scales, time lags in implementation; and economic, institutional and cultural barriers to change. The experience of NIDIS, FEWSNet and other information systems illustrate that early warning represents a proactive political process whereby networks of organizations conduct collaborative analyses. In this context, indicators help to identify when and where policy interventions are most needed and historical and institutional analyses help to identify the processes and entry points that need to be understood if vulnerability is to be reduced. Taking local knowledge and practices into account promotes mutual trust, acceptability, common understanding, and the community's sense of ownership and self-confidence (Dekens). As important as indicators are to such systems, it is the governance context in which EWSs are embedded that needs further attention, since, particularly for people-centered strategies at the so-called Last Mile, a mix of centralized and decentralized activities is required.

There is a critical need to approach early warning through an integrative approach by linking Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) (UNISDR, 2011; IPCC, 2011). This also requires an integrated risk approach, which translates climate change scenarios further, into risk, and vulnerability profiles that can serve as a basis to inform early warning systems and their set-up. The cases above, and other efforts, have demonstrated that social protection and early warning information interventions can provide disaster risk reduction while helping to meet the goals of adaptation to changes in extreme events. From a research and monitoring perspective efforts aimed at integrating social protection and early warning within international and national drought information system should:

- Strengthen the scientific and data foundations to support early warning for drought onset, severity, persistence and frequency
- Develop risk and vulnerability profiles of drought-prone regions and locales including impact of climate change adaptation interventions on food and water availability, access, and use
- Develop Indicators and methodologies to assess the value of environmental services, value and costs of environmental degradation, and impacts of water and crop subsidies.
- Better understand whether and how best to use probabilistic information with scenarios of potential surprise and cumulative risks at each scale
- Place multiple indicators within a statistically consistent triggering framework-cross-correlation among units before a critical threshold
- Frame the goals and objectives of international and country program intervention strategy
- Inventory and map local resource capabilities (infrastructure, personnel, and government/donor/NGO-supported services) available to complement food program operations
- Map decision-making processes and identify policies and practices that impeded or enable the he flow of information among information system components

Traditional assumptions are that effective functioning of early warning systems requires, firstly, prior knowledge of risks faced by communities and other users of the early warning information; secondly, a technical monitoring and warning service for these risks; thirdly, an effective strategy for dissemination of understandable warnings to those at risk; and finally, knowledge and preparedness to act (Traore and Rogers 2006). Two additional elements are now introduced: awareness that risks are changing (and which new risks may arise) and, especially, a way to communicate new knowledge about future conditions that can be understood and trusted (IFRC 2009; Pulwarty and Verdin 2011). As Dekens observes, this requires a long-term dialogue with communities and local institutions that may not immediately trust outside information about one of the few things they consider themselves experts on- what to expect from the local weather and climate.

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