Water Policy 18 (2016) 245–261

Strengthening drought risk management and policy: UNESCO International Hydrological Programme's case studies from Africa and Latin America and the Caribbean

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Abstract

Droughts have resulted in significant socio-economic impacts in the regions of Africa and Latin America and the Caribbean (LAC), especially in developing countries. The main gaps to mitigate its effects, identified in both Africa and LAC regions, include a lack of human and institutional capacity, a lack of access to relevant early warning information for decision-making, the identification of vulnerable communities within the countries and the integration of these two components into drought management policies. UNESCO International Hydrological Programme (UNESCO-IHP) has been providing support to enhance human capacity, policy guidance and tools to the countries to address drought-related challenges and this paper presents some examples. Through capacity building at regional institutions in Western, Eastern and Southern Africa, drought monitoring and early warning tools have been transferred and validated for inclusion into national climate risk management plans. In LAC, a drought atlas was produced to identify the frequency of meteorological droughts and the exposure of population to droughts. Also in LAC, national drought observatories were developed in two pilot countries, providing locally relevant and actionable drought monitoring and early warning information, socio-economic vulnerabilities and appropriate drought indicators for decision-making to strengthen current drought policies for these countries.

Keywords: Africa; Capacity building; Decision-making; Disaster; Drought; Early warning; Latin America; Risk management; Tools; UNESCO

Introduction

Climate change is likely to increase the frequency and magnitude of meteorological droughts (less precipitation) and agricultural droughts (less soil moisture) in presently dry regions by the end of the 21st century under the IPCC RCP 8.5 scenario (IPCC, 2014). This is also likely to increase the occurrences

doi: 10.2166/wp.2016.223

of short hydrological droughts (less surface and groundwater) (Lyon & DeWitt, 2012; IPCC, 2014; Masih *et al.*, 2014). Furthermore, the IPCC Fifth Assessment Report (IPCC, 2014) also emphasizes that impacts from recent climate-related extremes, such as heat waves, and droughts, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability.

Droughts are even more damaging in developing countries, where drought mortality is concentrated (UN, 2008). Absolute economic losses are largest in developed regions but in relative terms, developing countries are those suffering the biggest economic losses (UNISDR & CRED, 2015). In a number of countries, drought wiped out significantly more than 5% of the previous year's GDP (UN, 2008). In countries that rely heavily on agriculture, the impact of droughts on crop production can be disastrous for the economy as well as to low-income populations, often inducing famines in vulnerable communities (Guha-Sapir *et al.*, 2004).

Recent advancement in hydrological modelling, observation technologies, including from remote sensing, allows countries to develop or strengthen appropriate drought policies. Monitoring drought development and providing timely seasonal forecasts are essential for drought risk reduction and to address climate variability (Amissah-Arthur, 2003; Tarhule & Lamb, 2003; Hayes *et al.*, 2004; Hansen *et al.*, 2011; Sheffield *et al.*, 2014). Currently, there are a number of different global and regional drought monitoring systems developed by different institutions, such as the Global Drought Observatory (Vogt *et al.*, 2016), the African Drought Observatory (Sheffield *et al.*, 2014), the European Drought Observatory (Vogt *et al.*, 2011), the South Asian Drought Monitoring System (IWMI, 2015), the North America Drought Monitor (Svoboda *et al.*, 2002) and the SPEI Global Drought Monitor (Vicente-Serrano *et al.*, 2010), among others. However, integration of these tools into drought management policies, especially in countries from the developing world, still lags behind (e.g., Patt *et al.*, 2007). Additionally, these monitoring systems often focus on one aspect of drought, while drought management needs to address all affected sectors. To differentiate the types of drought impacts, they are often classified into meteorological, agricultural, hydrological and socio-economic droughts (UNISDR, 2007; Wilhite *et al.*, 2014). The challenge remains to address all these drought types simultaneously in a comprehensive drought management strategy.

Since 2013, and especially after the High-level Meeting on National Drought Policy (Sivakumar *et al.*, 2014), a greater awareness has been internationally raised to identify the gaps and needs at the national level regarding integrated drought risk management (IDRM). IDRM has been promoted as a response to move from crisis to risk management (Wilhite *et al.*, 2000, 2014; UNISDR, 2007), and aims at integrating the different components that are essential for an effective drought management. Baethgen (2010) identified four pillars to manage drought risks, these being: (a) identification of vulnerabilities and potential opportunities; (b) quantification of uncertainties in climate information; (c) identification of technologies and practices; and finally (d) identification of interventions, institutional arrangements and best practices. This IDRM approach is also comprehensively presented in the three pillars of IDRM (Figure 1). The first component of the IDRM focuses on monitoring and early warning capacities as the foundation of the drought plan. The second is linked with vulnerability/resilience and impact assessment in order to identify those areas and livelihoods which are most prone to the impact of droughts. Finally, the third component, mitigation and response planning, provides preparation and mitigation actions triggered by monitoring and early warning, prioritizing the most vulnerable areas.

Shifting from a crisis management approach to a proactive and more integrated risk-based approach is crucial in lowering the loss and damage resulting from droughts (Grobicki *et al.*, 2015). This requires the development of human and institutional capacities in the countries and design and implementation of

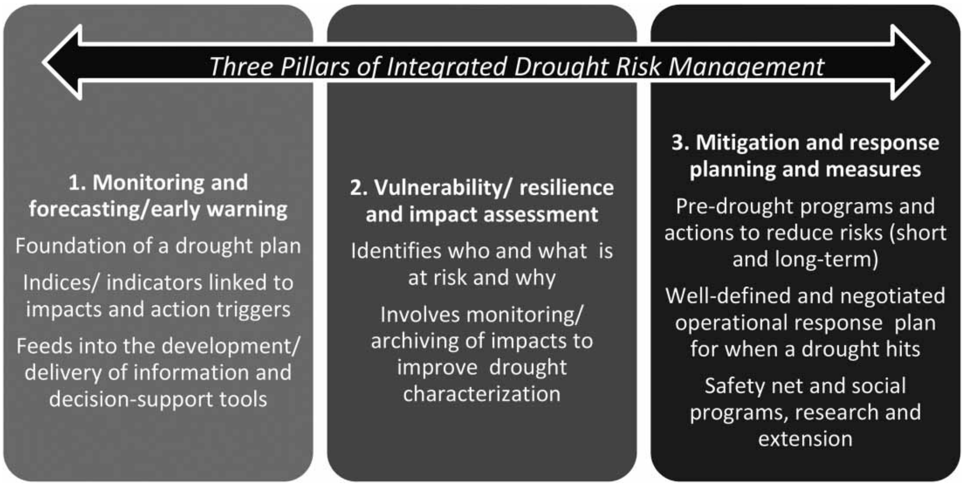

Fig. 1. The three pillars of IDRM (adapted from The World Bank Group, based on Gutierrez *et al.* (2014)).

adequate national drought policies. Moreover, because droughts do not respect boundaries and as they are a cause for migration (European Commission, 2015), international scientific cooperation is essential to achieve implementation of effective drought management policies.

In the case of Africa, historical evidence and general circulation models clearly show that the continent is experiencing increased droughts and aridity (Masih *et al.*, 2014). The projected combined impacts of climate change and population growth also suggest an alarming increase in water scarcity for many countries, with 22 of the 28 countries considered likely to face water scarcity or water stress by 2025 (Cooper *et al.*, 2008). The slow progress of drought risk management and the lack of adequate drought policies, along with increasing population and land degradation pose challenges to address the vulnerability of the region to drought impacts. Therefore, there is an urgent need in Africa to address human and institutional capacities to equip countries with means to shift towards a proactive drought risk management. In the Latin America and the Caribbean (LAC) region, there is a comparatively larger human capacity to develop effective drought monitoring and management solutions, but adequate tools and institutional capacity are still lacking, hindering the implementation of effective drought management and response systems.

This paper summarizes the current situation of drought management and policies in Africa and LAC, with emphasis on specific needs and gaps in both regions. It also focuses on UNESCO-IHP's contribution in strengthening the countries' capacities, and the specific drought management tools developed to support them, considering the different types of drought.

The UNESCO-IHP approach for drought management

The UNESCO International Hydrological Programme (UNESCO-IHP) is the only intergovernmental programme of the United Nations system devoted to the scientific, educational and capacity building aspects of hydrology. The UNESCO-IHP, through its Global Network on Water and Development Information in Arid Lands (G-WADI) and International Drought Initiative (IDI), supports the countries in identifying and addressing the drought management gaps and needs by strengthening global, regional and local capacities to manage water resources and by providing access to data and policy recommendations for a more integrated drought management. UNESCO also promotes international scientific cooperation to facilitate knowledge sharing and transfer for the optimal use of the available resources.

UNESCO-IHP collaborated with Princeton University in the development of an experimental drought monitoring and forecast system for Africa (Sheffield *et al*., 2014) and more recently for LAC, accessible at http://stream.princeton.edu/. The system tracks drought conditions in near real-time using remote sensing precipitation and atmospheric analysis data. The historic and real-time data are calculated using the Variable Infiltration Capacity (VIC) land surface hydrological model (Liang *et al*., 1994). This system allows monitoring of meteorological, hydrological and agricultural droughts in developing regions where institutional capacity is generally lacking and access to information and technology prevents the development of systems locally. It has the advantage of providing a standardized format for any of the components of the water balance, providing a comprehensive analysis for any point location within the Monitor's domain (currently covering Africa, LAC and the United States), while providing an overview of the regional, transboundary extent of drought hazards.

In a similar vein, UNESCO-IHP has collaborated with the Center for Hydrometeorology and Remote Sensing (CHRS), University of California, Irvine, on the development of tools to provide near real-time global satellite precipitation estimates at high spatial and temporal resolutions, including the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Cloud Classification System (PERSIANN-CCS) (Hsu *et al*., 2010). These tools include the G-WADI GeoServer (http://hydis.eng.uci.edu/gwadi/), that provides real-time precipitation estimates for water resources managers. By providing updated precipitation observations at the global level, the GeoServer is a direct support to meteorological drought monitoring and early warning worldwide, and a contribution to the Global Framework for Climate Services (GFCS) hosted by WMO (Hewitt *et al*., 2012).

Supporting drought risk management in LAC

Gaps and needs identified

The occurrences of drought hazards have been increasing significantly in LAC, affecting over 60 million people over the last three decades (EM-DATA, 2015). In order to move away from reactive crisis management and work towards proactive climate risk management, preventing and mitigating the impacts of drought is a top priority of many governments in the LAC region (Wieriks & Vlaanderen, 2015). This requires insight into the causes and characteristics of drought events and their processes, as well as the identification of the vulnerability of livelihoods to drought hazards. UNESCO-IHP has engaged with the countries to identify the most urgent needs and existing gaps of drought risk management, identifying several countries requiring the development of national drought monitoring and early warning systems (MEWS).

A common problem in LAC when developing these MEWS, is the decentralized data collection, scattered over multiple agencies that are dependent on different ministries. This requires collaboration across ministries through a multi-sectorial approach, which often cannot be effectively implemented without direct support from high-level policymakers. Although most countries have foreseen the development of such monitoring systems in their legislation, it often remains underdeveloped and inappropriate for decision-making.

A second problem in LAC that was identified during the development of these national monitoring systems and that is connected to the first, is the range of different data formats that need to be handled to allow integration of different data sources. MEWS require combining data sources from national weather and hydrological services, agricultural extension services and public databases, as well as data streams from international partners providing remote sensing datasets or global/regional weather and climate model outputs. This requires technological solutions that allow the integration of multiple data sources with different temporal and spatial resolutions. An additional challenge is that they often have a complex data structure and data exchange formats.

To develop the MEWS for this region, an important requirement is to provide actionable information for decision-making in order to become an effective tool in drought management and to be useful for drought policy. Data and information available in those MEWS should fulfil four conditions (adapted from Baethgen (2010)) as follows:

a) Updated: the drought hazard needs to be monitored in (near) real time.
b) Relevant: conditions of drought need to be detectable at the local (municipality) level.
c) Understandable: the drought information needs to be communicated in a format which is in line with the decision-making context.
d) Reliable: data sources need to be available continuously and need to be validated by the data source provider.

As an intermediate strategy, regional MEWS have been under development to support national governments with drought information over the last decade, but this approach poses its own problems. In most cases, regional systems have a strong bias in data provision, focusing on a particular aspect of drought (meteorological, hydrological or agricultural), and they are often too coarse to be actionable at the local scale. Therefore, the development of national MEWS remains a key challenge to connect the information available in those MEWS with effective drought policies.

We also identified drought vulnerability assessment, the second pillar of drought management (Figure 1), as a need for the region as it provides an essential link between MEWS and drought management and policy. If well-developed, the vulnerability maps of a country serve two purposes. First, they provide the means to quantify the differences in vulnerability between local communities, allowing the identification of those communities that need to be prioritized for the implementation of mitigation actions when droughts occur. Second, they can also provide a metric to validate the impact of public policy to reduce vulnerability when maps are updated regularly. By comparing successive vulnerability maps, the vulnerability index of individual communities should progressively become lower in those localities where governmental policies have been implemented. Used in such a way, these vulnerability maps have the potential to become a strong instrument to steer and adjust public spending to effectively improve drought resilience of vulnerable communities. They are also helpful to inform society on the impact of national drought management policies and public drought mitigation programmes. Nevertheless, few countries have currently developed such vulnerability analyses at the national level. In Mexico, the National Drought Programme PRONACOSE (Federman *et al.*, 2014) was launched as one of the first integrated drought management plans at the national scale in the LAC region. This programme has advanced significantly to identify drought vulnerabilities in a standardized, comparable manner, incorporating drought policy explicitly in its framework. Other recent examples include Peru (MINAGRI, 2012), Northeastern Brazil (De Nys & Engle, 2015) and Ecuador (Ycaza *et al.*, 2012).

Drought management policies exist in most LAC countries, but are often loosely tied to objective indicators, making it difficult to generate a standardized response to reach the most vulnerable populations proactively and, as such, have no feedback mechanism to adjust the policies. As an example, the 2016 Peruvian Drought Management Plan (MINAGRI, 2016) that was developed as a response to the 2015–2016 El Niño event, indicates a set of actions to be taken proactively to mitigate the impact of drought, suggesting that the Standardized Precipitation Index (SPI) (McKee *et al.*, 1993) should be used to trigger those responses, without indicating what threshold should be used. Additionally, SPI only considers meteorological aspects of drought, making the indicator less useful to monitor potential impacts of agricultural and hydrological aspects of drought. A similar gap has been identified in the drought declarations of the Chilean Ministry of Agriculture, that uses a range of indicators to identify hotspots of drought at the communal level, but the final area that will be declared for receiving financial support is defined by local and regional policymakers. This has resulted in significant over-allocation of resources to regions that have only suffered mild impacts of (meteorological) droughts, urging a revision of the current declaration procedure based on objective indicators.

The above description indicates that different aspects of drought management have been developed in the different countries, but the challenge to integrate the different components, as defined in Figure 1, to work seamlessly in a national integrated drought management strategy is still needed.

In order to identify the needs and gaps in drought management and the means to address them, UNESCO-IHP and its partners organized the International Symposium on Drought Management Tools in 2014 in Santiago de Chile to identify advances of the different countries and to identify remaining gaps and needs. As an outcome of the meeting, the Santiago Declaration on Drought Management Tools was established. This defines a roadmap for action in the region, identifying a set of remaining gaps to be addressed:

(a) the lack of effective agricultural drought monitoring indicators in current drought monitoring tools;
(b) that drought-related information should be made available with sufficient detail, equally considering spatially and temporally well-distributed hydro-meteorological data and the local water demand/abstractions as an integral component of hydrological drought management;
(c) that in areas with steep topography and/or snow, groundwater and reservoir storage, these indicators need to be considered in hydrological drought assessment and management;
(d) a knowledge gap in currently available socio-economic indicators for drought monitoring, which are essential to establish a clear evaluation of long-term drought impacts and to allow assessing the cost of inaction;
(e) that drought impacts communities depending on their vulnerability, and that there is a need to identify the vulnerability of communities as an integral part of national socio-economic drought management;
(f) that there is a need to shift from reactive drought crisis management towards proactive drought risk management and to identify a central role of drought MEWS to trigger proactive responses;
(g) that regional and global drought monitoring and early warning tools are useful, but that there is a need for local calibration and validation of these products to support drought management at the watershed level.

Tools and solutions provided in LAC

Based upon the gaps identified in the previous section, the UNESCO-IHP strategy consisted in supporting the countries to reduce these gaps through its G-WADI and IDI activities focused on institutional capacity development and the development of adapted tools and solutions to provide drought information and to support IDRM. Notably, effective drought MEWS have been developed to increase drought management capacities at the regional, national and watershed level in LAC.

Development of regional drought tools for LAC. At the regional level, a drought monitoring and flood forecast system for LAC was developed by Princeton University with the support of UNESCO-IHP, with similar characteristics as the African version (Sheffield *et al.*, 2014). It provides information on current and expected drought (and flood) conditions. Based on micro-scale hydrological modelling (Liang *et al.* 1996), the system analyses available data to provide real-time assessment of the water cycle and drought and flood conditions, and puts this in the context of the long-term record dating back to 1950. The Flood and Drought Monitor can be accessed from http://stream.princeton.edu/. The portal holds information on precipitation, temperature, radiation and wind speed, drought indicators (SPI, soil moisture, NDVI, evapotranspiration) and flood indicators (surface runoff and streamflow). The information can be obtained either spatially or for point locations (Figure 2), for specific dates, months or annual timescales, and is compared with the normally expected conditions or percentiles. The Flood and Drought Monitor system also produces short and longer seasonal forecasts.

Complementary to the Drought Monitor, UNESCO collaborated with the countries in the LAC region to develop a regional drought atlas. The atlas identifies the drought frequency using a regional frequency analysis with L-moments (Hosking & Wallis, 2005), which is the probability of drought occurrence with a certain magnitude and duration at any given place in the area of interest. This methodology was first used in the US Drought Atlas (Willeke *et al.*, 1994), and further elaborated to construct the Chilean Drought Atlas as a pilot version (Nuñez *et al.*, 2011). This methodology was further expanded to cover the whole LAC region (Nuñez *et al.*, 2016). The Drought Atlas for LAC contributes to identify the livelihood vulnerability providing an effective tool to raise awareness on the exposure to drought. It also identifies the variability of rainfall deficits in countries of LAC and allows visualizing how climatic

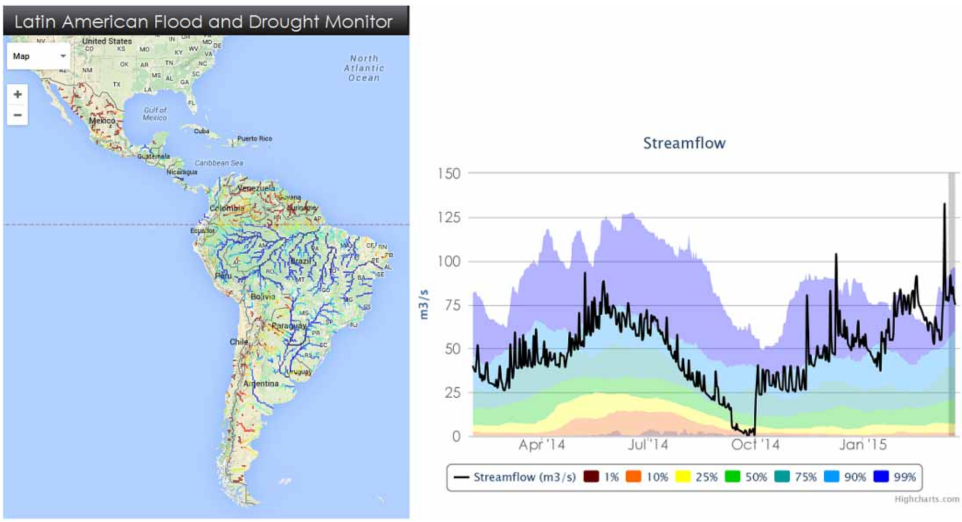

Fig. 2. The Latin American Flood and Drought Monitor system, showing the average daily streamflow and its corresponding historic values expressed as percentiles.

variability differs spatially within the countries, even at short distances. Specific deliverables focus on hazard maps for precipitation deficit (drought) and excess (floods). Additionally, the atlas can be used to support decision-making for drought risk management by answering the following questions: ‘How rare is the current drought?’ ‘How large a drought should we plan for?’ and ‘How rare is the drought of record?’ The atlas can be accessed at www.climatedatalibrary.cl/CAZALAC/maproom/.

Establishment of national drought observatories in pilot countries. While data and information are often available from national and international data sources on drought hazards, these are not always provided in a relevant, timely and actionable manner. With the development of national drought observatories, informed decision-making related to droughts, as well as other climatic hazards such as heat waves, frost and extreme rainfall events, is made possible. In this manner, vulnerability to droughts and other agroclimatic events can be reduced by providing relevant and rapid information to allow timely responses.

In close collaboration with the Chilean Ministry of Agriculture, the Food and Agriculture Organization (FAO) and the International Research Institute for Climate and Society (IRI), the Chilean Agroclimatic Observatory (www.climatedatalibrary.cl/UNEA/maproom/) was launched in June 2013. The observatory is a collection of maps and other figures that monitors present drought conditions. It provides near-future seasonal forecasts and allows putting the current droughts into a historical context (Figure 3). The system allows the creation of compound indices, taking into account a number of

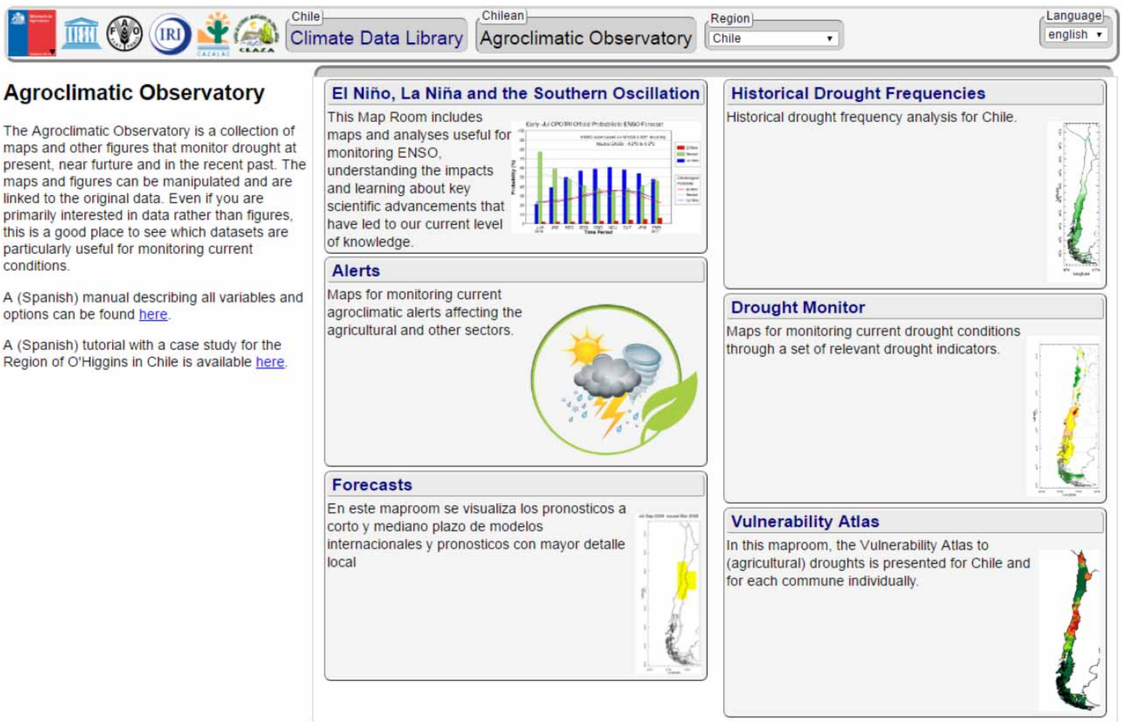

Fig. 3. Interface of the Chilean Agroclimatic Observatory, showing the different components: present drought conditions and alerts, near-future seasonal forecasts, historical drought analyses, ENSO observations and impact data, as well as drought vulnerability maps.

different drought indicators at the same time; information that helps to avoid false alarms for drought events arising as a result of external causes such as crop diseases, wildfires, etc.

The Chilean Agroclimatic Observatory builds upon the Climate Data Library (CDL), a tool that allows the collection of all raw databases of national and international institutions relevant to drought monitoring (Del Corral *et al.*, 2012). Data of numerous formats can be added, with which additional indicators can be calculated using advanced arithmetic or geo-statistical functions. In order to provide effective decision support tools, a user-friendly interface was built on top of the CDL, called the 'map-room', which holds relevant drought indices on meteorological, hydrological and agricultural drought, and combines information from national and international datasets.

A similar process was followed in Peru, where a consortium of partners developed the National Drought Observatory (ONS in Spanish) using the same CDL technology, accessible at http://ons.snirh.gob.pe/Peru/maproom/. The ONS has been fully integrated in the National Water Resources System (SNIRH), becoming a cornerstone of its drought management strategy. The system collects daily levels of rivers, reservoirs, streamflow, hydropower production, precipitation, temperature, vegetation conditions, as well as information on past droughts (the Peruvian Drought Atlas) and near-future seasonal forecasts. It also has a particular focus on El Niño Southern Oscillation (ENSO), due to the high correlation between droughts in the country and the ENSO phenomenon.

Remote sensing data are a key component of these observatories in both Chile and Peru. To provide tailored satellite precipitation estimates for these pilot countries, UNESCO-IHP collaborated with its partners to develop calibration methodologies for the G-WADI GeoServer developed at CHRS, University of California. Using a quantile mapping and Gaussian weighting interpolation approach, the biases could effectively be removed, providing a near real-time daily precipitation estimate for Chile coherent with observed values from more than 400 rain gauges (Yang *et al.*, 2016).

A more recent component of UNESCO-IHP efforts focused on the vulnerability and drought impact assessment (Figure 1), supporting the development of an (agricultural) drought vulnerability atlas for Chile. The focus was put on the vulnerability of rural communities using indicators related to agricultural production and rural poverty. Sixteen indicators were used to calculate the overall agricultural drought vulnerability map (Figure 4), grouped into three categories (Sensitivity, Exposure and Adaptation Capacity) and covering socio-economic, biophysical and institutional aspects. The individual indicators, as well as the final vulnerability maps are all accessible through the Chilean Agroclimatic Observatory.

In order to provide an objective and actionable drought index, information from meteorological, hydrological and agricultural drought indicators were integrated into a combined drought index (CDI) for Chile (Figure 5), which was based upon the CDI developed for the European Drought Observatory (Sepulcre-Canto *et al.*, 2012). For the Chilean CDI, the underlying indicators and their thresholds were calibrated using drought impact information obtained over the 2008–2015 period and validated with claims of crop losses from agricultural insurance policies over the same period (Agroseguros, 2016). As such, the resulting CDI provides three standardized drought alert phases that are defined by their drought intensities (Figure 4). By standardizing these alert phases for the whole country, the implementation of a more objective drought management response is made possible.

Impact on drought policy in pilot countries of LAC

The different activities implemented along the three pillars of IDRM (Figure 1) have impacted drought policy in LAC along different pathways. The regional monitor has been transferred and

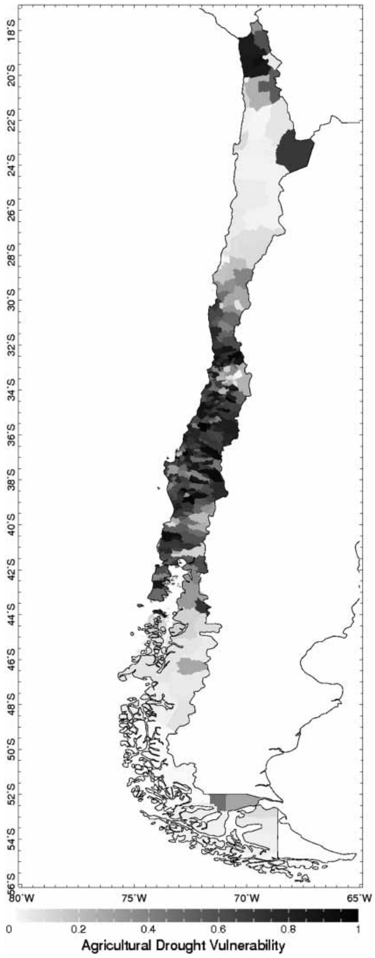

Fig. 4. The Chilean Agricultural Drought Vulnerability map.

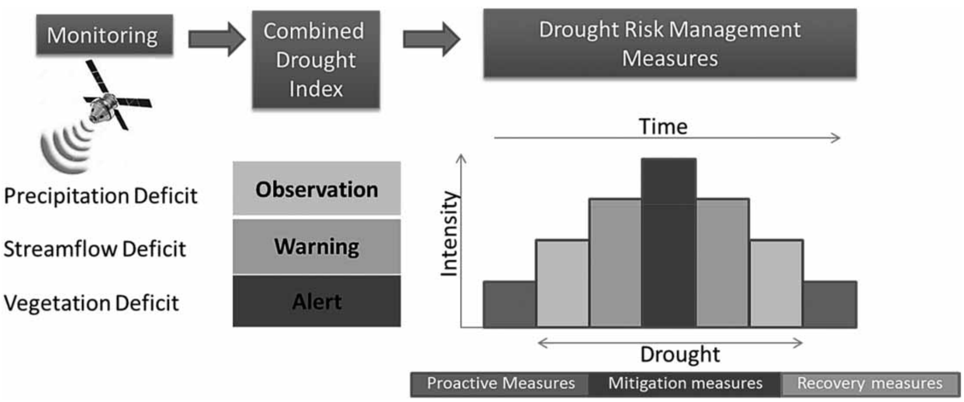

Fig. 5. The CDI for decision-making.

tested by 22 hydrometeorological agencies from countries of LAC for operational use. Currently, the flood and drought monitor system is being integrated in the national meteorological and water resources agencies in Bolivia, Chile, Ecuador, Peru and Uruguay. In addition, both in Chile and Peru, the national observatories have been adopted in the most recent national drought policy plans (e.g., MINAGRI, 2016) as tools to steer agricultural drought mitigation protocols. In the case of Peru, this has led in 2016 to the integration of the drought response measures into the ONS, showing a feedback mechanism of how the third pillar on drought measures and policy can be coupled to drought MEWS.

The Drought Atlas is also incorporated in the monthly 'Agroclimatic Outlook' provided by the Chilean Ministry of Agriculture. This allows the current droughts to be put into context by expressing the rainfall deficit in terms of return periods (for example, 'the reduced rainfall amount this last month occurs every 5 years on average'). This way, drought indicators become more actionable, as the data are translated into a product which is easily understandable by policy and decision-makers. Drought indicators also highlight the events which are unusual or extreme, raising awareness on natural variability by correcting the false perception that droughts are more recurrent and more severe than normally expected.

The more recent development of vulnerability maps for agricultural drought in Chile is providing a more socio-economic approach to drought management, and a very promising link between the biophysical work on objective drought indicators and the policy aspects of drought management. This allows identification of the areas in which to prioritize proactive drought measures, as the communities that are hardest hit by drought are identified. In this respect, it is expected that the Chilean Vulnerability Atlas will eventually become a tool to validate the impact of drought policies aiming at increasing the resilience of vulnerable communities and to tackle intermediate aspects that are relevant in a drought context (poverty, education, access to water, health coverage, investments in R&D, etc.). In this way, the atlas also contributes to the overall 2030 agenda aiming to reduce poverty.

Finally, the CDI was developed in 2016 in collaboration with the Chilean Ministry of Agriculture as a key component to streamline the (agricultural) drought declarations and to provide a baseline to identify a minimum number of affected communities, based on objective drought indicators. This shows a direct pathway of how MEWS can become an integral part of drought policy and management.

Supporting drought risk management in Africa

Gaps and needs identified

Drought is one of the leading impediments to development in Africa (African Risk Capacity, 2015). Much of the continent is dependent on rain-fed agriculture, which makes it particularly susceptible to climate variability (Cooper *et al.*, 2008). Prolonged and frequent occurrences of droughts present significant challenges to agriculture, forestry, water resources management, urban planning and food security. Southern Africa has been experiencing since 2015 a drought caused by the El Niño phenomenon, and which led to the declaration of a state of emergency by many countries in the sub-region (FEWS-NET, 2016). In 2010–2011, a drought occurred in Eastern Africa, considered to be the worst drought in 60 years, affecting more than 13 million persons within the sub-region, and causing the loss of lives and livelihoods (IGAD, 2013).

Monitoring drought and providing near real-time and seasonal forecasts are essential for an IDRM and risk reduction in Africa (Tadesse *et al.*, 2008). Drought monitoring over Africa is challenging because of the sparseness of observational data, either historically or in real time. Currently available approaches in Africa are very limited, in part because of unreliable monitoring networks. Operational seasonal climate forecasts are often reliant on statistical regressions, which are unable to provide detailed information relevant for drought assessment (Patt *et al.*, 2007; Sheffield *et al.*, 2014). However, the wealth of data from satellites and recent advancements in large scale hydrological modelling and seasonal climate model predictions have enabled the development of state-of-the-art monitoring and prediction systems that can help address many of the problems inherent to drought-prone regions in Africa. Satellite remote sensing combined with ground truth data and modelling is capable of overcoming differences in data gaps across political boundaries that have historically hindered drought monitoring in Africa (Grimes & Diop, 2003; Grimes *et al.*, 2003).

Mitigating the impacts of droughts and famine is one of the primary aims of many governments and humanitarian organizations in the African region, which requires considering the resilience of communities. However, it cannot be effective if the causes and characteristics of drought events and processes are not well understood. To this end, a drought monitoring system is essential to assist water users in making climate-informed decisions (Diouf *et al.*, 2002; Hellmuth *et al.*, 2007; Cooper *et al.*, 2008).

Many areas in Western, Eastern and Southern Africa, particularly the arid and semi-arid areas are drought-prone areas. Regional institutions have been put in place in Western, Eastern and Southern Africa to address the challenges caused by recurrent droughts. In West Africa, the Inter-State Permanent Committee to Combat Drought in the Sahel was established in 1974, following the devastating droughts of 1973–1974, with its two technical specialized agencies, namely, AGRHYMET for agro-hydro-meteorological monitoring and capacity building and the Institute of Sahel (INSAH) for socio-economic related dimension. Member Countries of the Permanent Interstates Committee for Drought Control in the Sahel (CILSS) include Benin, Burkina Faso, Cape Verde, Chad, Cote d'Ivoire, Gambia, Guinea, Guinea Bissau, Mali, Mauritania, Niger, Senegal and Togo. In response to the devastating weather-related disasters, countries in Eastern and Southern Africa established in 1989 a Drought Monitoring Centre with its headquarters in Nairobi (DMCN) and a sub-centre in Harare (Drought Monitoring Centre Harare, DMCH). The DMCN was adopted later as a specialized institution of Intergovernmental Authority on Development (IGAD) and became the IGAD Climate Prediction and Applications Centre (ICPAC). DMCH was replaced by the Southern Africa Development Community (SADC) climate service centre covering 15 countries (Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe). The IGAD region comprises eight countries within the Greater Horn of Africa (GHA) including Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan, South Sudan and Uganda. The region has about 60% of the land classified as arid. Following the 2010–2011 droughts in Eastern Africa, the countries of the sub-region adopted the IGAD Drought Disaster Resilience and Sustainability Initiative (IDRISSI) to end drought emergencies within the sub-region, with emphasis on building resilience of communities and promoting equitable and significant disaster risk management, preparedness and effective response in the IGAD region.

One of the objectives of these regional climate-related institutions is to provide appropriate and timely climate early warning information and support specific sector applications for the mitigation of the impacts of climate variability and change for poverty alleviation, management of environment and sustainable development. These centres are producing and disseminating climate products to various users, including decadal, monthly climate bulletins and already for more than a decade the climate outlook, which includes climate seasonal forecasts with a focus on the expected precipitation for the rainy seasons (Patt *et al.*, 2007). Despite the data and information platforms put in place by these regional centres, there is still a need for more data and analysis tools at the regional level to complement existing systems. Particularly, near real-time and seasonal forecasts of climate extremes, including droughts and floods, are still lacking. The main gaps facing African countries are related to data and human capacity. Hydrometeorological networks have been deteriorating over the last decades, impacting the quality of the climate information for decision-making. Also, the different regional centres and national meteorological and hydrological services in many African countries are generally lacking skilled and sufficient human resources for addressing drought-related challenges.

Tools and solutions provided in Africa

The African Flood and Drought Monitor, developed by Princeton University with the support of UNESCO-IHP, was deployed in 2010 in combination with extensive training in Western Africa in 2011 and 2013 and in Eastern Africa in 2012 (Sheffield *et al.*, 2014). An extension of this work to include the Southern Africa sub-region is planned for the end of 2016. In West and Eastern Africa, the deployed drought monitor has been providing near real-time information on drought conditions (soil moisture indexes and discharges) and is used as complementary information to the existing monitoring systems at AGRHYMET (Diouf *et al.*, 2002) and ICPAC, thus improving their monitoring capabilities.

In addition to the drought monitor system, the G-WADI GeoServer near real-time rainfall estimation developed by the CHRS of the University of California, Irvine has been used by AGRHYMET in West Africa and Namibia as complementary information for drought and flood monitoring. UNESCO-IHP has also deployed in Eastern Africa the hydrological seasonal forecast approach already used in West Africa which is now being considered within the climate outlook forums in the region.

Impact on drought policy in pilot countries of Africa

Most of the important perennial rivers and streams of Namibia have their origin outside of the country: the Kavango, Kwando and Zambezi rivers in the northeast originate in Angola and Zambia, while the Orange River in the south originates in Lesotho and South Africa. Water resources planning and emergency preparedness for floods and droughts requires information on upstream conditions of these rivers. As one important tool in such information gathering, the Namibia Hydrological Services (NHS) of the Ministry of Agriculture, Water and Forestry incorporates precipitation estimates from the G-WADI GeoServer. In conjunction with limited stream gauging data, GeoServer information assists the NHS to make more accurate judgements as to future water supply for multiple uses, and provides early warning for floods and droughts in areas located in these and other national and transboundary river basins. The flood bulletins and other flood information are made available on the Namibia Flood Dashboard (http://matsu.opencloudconsortium.org/namibiaflood) and disaster-related information is made available by the Namibian Directorate of Disaster Risk Management (http://www.ddrm.gov.na/).

The current African drought monitoring system has been installed and used at regional level by the different regional centres to complement their existing monitoring systems. An essential component to ensure actual uptake of this climate information for decision-making is capacity building and outreach to decision-makers and farming communities (Patt *et al.*, 2007; Cooper *et al.*, 2008). Therefore, UNESCO-IHP has focused on training of the national hydrological and meteorological services, as well as the regional centres, to empower them with the tools to further develop and adapt the drought monitor by incorporating national datasets available within the countries and the centres. This, in turn, should contribute to improve the quality of the information provided at national and local levels and strengthen the human capacities in those countries directly to disseminate the improved information on climate-related disaster risks to the regional, national and local levels.

Conclusions

The severe impact of droughts on vulnerable communities in the Latin American, Caribbean and African regions urge the adoption of an integrated climate risk management approach (Figure 1) that focuses on proactive drought management and policy. This approach consists in the development of monitoring and early warning tools, combined with the assessment of the vulnerabilities of local communities to droughts, and by integrating proactive planning and mitigation measures into national drought policies.

UNESCO-IHP, through its G-WADI and IDI activities, supports the countries in these regions by identifying the needs and gaps for an integrated drought management and aims in filling those gaps by providing the countries with tools, data and methodologies and by providing platforms for international scientific and political cooperation.

A set of regional tools was developed for this purpose, including the high spatial and temporal resolution global precipitation estimates from satellite data (the G-WADI GeoServer), a regional drought and flood monitoring monitor for both the African and LAC region, and a regional drought atlas for LAC. At the national level, examples of national drought observatories were developed for pilot countries (Chile and Peru) as case studies covering all three components of IDRM. In these platforms, both globally available and local datasets can be combined and integrated providing a more tailored environment focused on the needs of local decision-makers. A pilot vulnerability assessment was also developed for one of the countries, providing relevant information regarding actual drought policy and mitigation instruments, as well as allowing identification of those communities that still are vulnerable to current and future climatic variability and change. Finally, drought policies are under development in these two countries that integrate the objective drought indicators provided through monitoring and early warning, in order to streamline the national response to drought hazards and to allow proactive drought measures to be implemented.

Nevertheless, significant challenges still remain in the Latin American, Caribbean and African regions that need to be addressed, many of which were summarized as part of the Santiago Declaration. Technology transfer and capacity building of local human resources in those regions remain essential to empower further development and uptake of the integrated drought management approach, and are part of the mandate of UNESCO-IHP. An additional focus area includes local calibration and validation of currently available (regional) drought information, to ensure reliable early warning and forecast at the local level, which is currently under development with support from the countries from these regions.

Acknowledgements

The authors wish to recognize Princeton University, the Centre for Hydrometeorology and Remote Sensing (CHRS), University of California at Irvine and the International Research Institute for Climate and Society (IRI) at Columbia University for their collaboration with UNESCO-IHP. The authors wish also to thank their colleague Yo Nishimura for his revision and valuable suggestions in reviewing and formatting this paper.

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