IMPROVED DROUGHT EARLY WARNING AND FORECASTING TO STRENGTHEN PREPAREDNESS AND ADAPTATION TO DROUGHTS IN AFRICA

DEWFORA

A 7th Framework Programme Collaborative Research Project

Methods for mapping drought vulnerability at different spatial scales

WP3 - D3.2

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SUMMARY

The objective of the vulnerability assessment is to identify underlying causes of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. Vulnerability refers to the characteristics of a group in terms of its capacity to anticipate, cope with, resist and recover from the impact of drought. Vulnerability assessment is to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors.

The consequences of droughts can usually be predicted, but drought vulnerability -- that is the reasons that make a system suffer – are poorly understood. Therefore preventive action is frequently absent or insufficient to mitigate serious impacts in many regions. Here we aim to understand vulnerability in order to provide information for the design of early warning systems in the next steps of the DEWFORA project.

This report examines African patterns of drought vulnerability through the mapping of several drought-related indicators – either at a country level or at regular grid scales. The proposed methods for mapping drought vulnerability at different spatial scales include characteristics that cover various aspects of droughts – from meteorological and hydrological drought hazard to social vulnerability.

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1. INTRODUCTION AND PURPOSE

1.1 OBJECTIVES OF D3.2

The objective of the vulnerability assessment is to identify underlying causes of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. Vulnerability refers to the characteristics of a group in terms of its capacity to anticipate, cope with, resist and recover from the impact of drought. Vulnerability assessment is to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors.

The consequences of droughts can usually be predicted, but drought vulnerability -- that is the reasons that make a system suffer – are poorly understood. Therefore preventive action is frequently absent or insufficient to mitigate serious impacts in many regions. Here we aim to understand vulnerability in order to provide information for the design of early warning systems in the next steps of the DEWFORA project.

This report examines African patterns of drought vulnerability through the mapping of several drought-related indicators – either at a country level or at regular grid scales. The proposed methods for mapping drought vulnerability at different spatial scales include characteristics that cover various aspects of droughts – from meteorological and hydrological drought hazard to social vulnerability.

1.2 ONGOING EFFORT

The aim of this report is to start a process of vulnerability evaluation that will be completed during the time of the DEWFORA project. It is important to emphasize the word ‘start’, because the number of drought vulnerability aspects and indicators is potentially quite large. This report is a starting point for discussion and it is an ongoing effort that will be revised and reviewed thought-out the project. The limited set of results presented and analyzed in this report may, with subsequent contributions from other research groups, develop into a comprehensive African drought vulnerability assessment.

1.3 ADDRESSING COMPLEXITY

Drought has multiple and severe social and economic impacts in any regions, therefore drought vulnerability is hard to quantify because the vulnerability aspects are more complex than in other natural phenomena. The magnitude of drought vulnerability is determined, in addition to the natural hazard and exposure, by the level of development, population density and structure, demands on water and other natural resources, government policies and institutional capacity, technology, and the political system, among others.

1.4 STRUCTURE OF THE REPORT

Here we propose a range of indicators to evaluate the drought vulnerability. Indicators can be evaluated at the case study resolution, or at the continental level. A survey of previous studies frames the approach followed in this study (Section 2). The methodological contribution of our assessment is to follow a risk based approach to evaluate drought vulnerability, since the mapping results will then be used in DEWFORA to develop threshold levels of risk in early warning systems (Section 3).

At the continental level, vulnerability maps are produced by integrating a number of publicly available global datasets (Section 4 and 5). At the case study level, guidelines are provided to derive vulnerability indicators with the participation of stakeholders (Sections 6). The discussion of the selected indicators allows a number of policy relevant messages to be extracted (Section 7).

2. A SURVEY OF PREVIOUS AND ONGOING EFFORTS

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 a drought as an individual natural disaster and as a global multifaceted phenomenon (IMWI, 2009). Some studies (Samtkin et al. 2008; O'Brien et al., 2010) believe that lack of a common understanding of what drought is stands in the way of cohesive anti-drought action. Beyond semantics, it is clear that African countries and societies are among the most vulnerable in the world, and there are many ongoing efforts to define the causes and consequences of African vulnerability to drought. A comprehensive evaluation of the 807 drought and 76 famine entries from 1900 to 2004 in the EM-DAT database (Emergency Events Database: www.emdat.be/) revised by Below et al. (2007) estimated that more than half take place in Africa.

Smatkin et al. (2009) illustrated 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. Dai et al. (2004) developed a global monthly dataset of the Palmer Drought Severity Index

(PDSI) for 1870-2002 and established that very dry areas had more than doubled since the 1970s, with acute increases in Africa. Dettinger and Diaz (2000) used monthly streamflow series to characterize and map global geographic differences in the seasonality and annual variability of streamflow; here again, Africa is highlighted as the continent with highest vulnerability.

Vicente Serrano et al (2012) analysed the challenges for drought mitigation in Africa highlighting the value of geo-statistical data and drought information systems. The study provides information both at the continental level and in a Kenya case studies, providing data on drought episodes.

The social aspects of vulnerability have also been studied. Yohe and Tol (2002) proposed a method for developing indicators for social and economic coping capacity in the context of climate change. Later, a simple index to quantify adaptive capacity was used by Ionescu et al (2007) including only GDP, literacy rate, and labour participation rate of women. Yohe et al. (2006) used the Vulnerability-Resilience Indicator Prototype (VRIP) developed by Brenkert and Malone (2005) as a proxy to adaptive capacity index, considering the capacity to adapt to environmental change as implicit in the vulnerability assessment. Iglesias et al (2007a) develop an Adaptive Capacity index (AC index) with three major components that characterize the economic capacity, human and civic resources, and agricultural innovation. And a similar approach has been taken in the context of drought (Moneo, 2007). The approach is flexible and can be applied to managed and natural ecosystems as well as to socio-economic systems. Iglesias et al. (2009; 2011, 2012) defined an index of social vulnerability by combining the vulnerability derived from the direct exposure to drought, and vulnerability to drought derived from social and economic aspects. For example, given a specific farm, the vulnerability is directly related to the intensity of the drought event. In contrast, given a defined drought event, the most vulnerable farming system is the one that has less social and economic resiliency; in general marginal and poor farming systems suffer the largest consequences of drought.

Global drought vulnerability is a key element in several major global projects. The Climate Impact on Agriculture (CLIMPAG) project of the FAO has carried out an analysis of rainfall variability and drought for the period 1961-2002 and presented results through time series maps. The Natural Disaster Hotspots project of the World Bank has assessed the global risks of two disaster-related outcomes - mortality and economic losses - by considering physical exposure and historical loss rates (Dilley et al. 2005). The Global Water System Project (GWSP) examines global water assessment indicators with links to poverty and food security.

The Global Drought Monitor of the University College London, UK, evaluates drought vulnerability based in publicly available datasets. The International Research Institute for Climate and Society of Columbia University, USA (IRI) monitorises global drought based on the SPI index and issues climate forecasts and the European Centre for Medium-Range Weather Forecasts (ECMRW) also includes a global meteorological drought analysis. The USGS drought monitor is included in the FEWS early warning systems.

The most comprehensive effort in water resources analysis – including many aspects of drought vulnerability – is carried out by the UNH Water Systems Analysis Group of the University of New Hampshire, USA has developed a compendium of Earth System and socio-economic databases describing the current state of global water resources, including associated human interactions and pressures. The group cooperates with several UN agencies and NASA to integrate a wide array of satellite-derived and land-based monitoring products from around the world with regional and country-level socio-economic data. This group has produced a digital archive presenting more than 130 thematic global datasets facilitating indicator calculation and mapping (WWI mapping) that are very relevant to drought vulnerability.

Current mapping exercises have barriers and opportunities. A limitation of the mapping efforts and the vulnerability evaluation is the limited in-country information resources; this information shows an alarming severe decline in the last two decades of the 20th century, particularly in Africa (IAHS 2001). At the same time, state-of-the-art data sets from the Earth Systems Sciences, offers an opportunity to vulnerability evaluation, linking social and environmental aspects (Vörösmarty 2010; Barboso, 2011).

Climate change will increase vulnerability. Burke et al. (2006) found that at present climate conditions, on average, 20% of the land surface is in drought at any given time while the proportion of land surface in extreme drought is predicted to increase from 1% at present to 30% by the end of the twenty-first century.

Annex 1 provides maps as examples of the current state-of-the-art in drought mapping.

3. EVALUATING VULNERABILITY IN A RISK BASED APPROACH

The objective of the vulnerability assessment is to identify underlying causes of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. Vulnerability refers to the characteristics of a group in terms of its capacity to anticipate, cope with, resist and recover from the impact of drought (Iglesias et al., 2009). Vulnerability assessment, therefore will identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. Social vulnerability to drought is complex and it is reflected by society's capacity to anticipate, cope with and respond.

We evaluate drought vulnerability based on the concepts that appear in most policy documents, following the definitions provided by the United Nations International Strategy for Disaster Reduction (UNISDR, 2006). Each drought (from the physical point of view) is characterised by its location, intensity, frequency and probability. The conceptual aporach is summarised in Figure 1. Drought vulnerability considers the set of conditions and processes resulting from physical, social, economic, and environmental factors, which increase the susceptibility or potential impacts of a community to the impact of drought. Positive factors, that increase the ability of people and the society they live in, to cope effectively with drought and can reduce their susceptibility, are often designated as capacities. Risk is then the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between the natural hazard and vulnerable conditions. The characterisation of drought hazard is a complicated task, primarily because drought is a complex natural phenomenon difficult to detect. Several methodologies have been proposed for drought characterisation, based either on the consequences or on especially devised indices (Wilhite, 2005 and 2006; Iglesias et al., 2009).

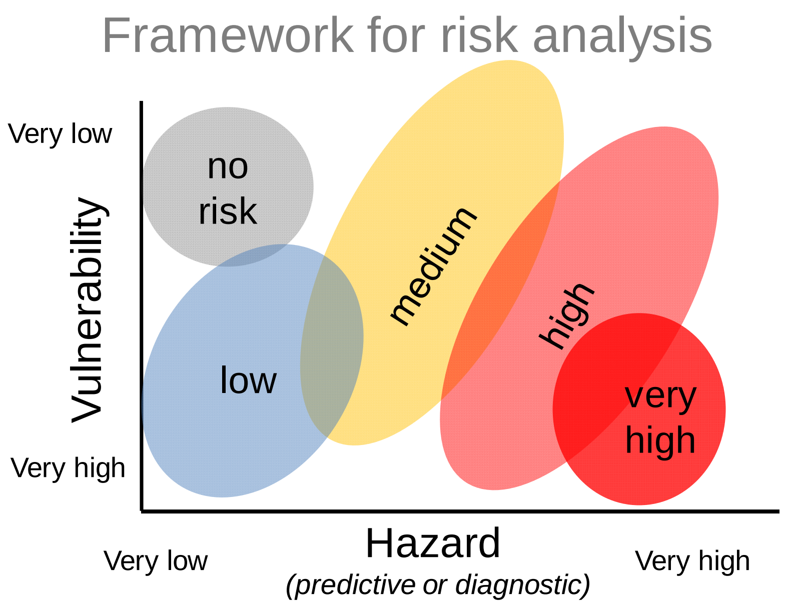


Figure 1 Conceptual framework

The key concepts in our approach are: (1) risk relates to the consequences of a perturbation, rather than its agent; and (2) risk is a relative measure and critical levels of risk must be defined by the analyst. It is important to clarify that uncertainty refers to the imperfect knowledge of the probabilities of drought and risk refers to the uncertain consequences of drought.

Within DEWFORA we will estimate these aspects of social vulnerability, evaluating the natural resource structure, the economic capacity, the human and civic resources, and aspects of technological innovation. Furthermore, their strong spatial variability, which is a particular characteristic of Africa, will be accounted for. These factors will be components of a vulnerability index and they can be weighted appropriately in computing the final value of the index. Weighting of the components will be carried out by a consultation with the stakeholders involved in the case studies.

Selecting the indicators for risk analysis is a task that requires careful attention, since the indicators are sector/system specific and they need to represent some aspect of observed impacts, risk level, and vulnerability reducing targets. In all cases, multiple indicators are needed.

3.1 DEFINING VULNERABILITY THRESHOLDS

Developing Early Warning Systems requires a connection between forecasts and vulnerability. This connection is, where a forecast may become a warning and where it starts to make societal impact. A proper translation of forecasted variables into a potential economic or societal impact needs to be made. Figure 2 shows a conceptual sketch of how a decision on action based on an early warning is made. Under "normal conditions", average climate is expected. The "coping range" of society may be described as the maximum perturbation form mean conditions that can be accepted without significant damages. If a probabilistic description of average climate is available, coping range may even be expressed in terms of a frequency factor in units of standard deviations. The hazard of a damaging event would be the probability of having to face, in a given period of time, climatic conditions stronger that the coping capacity. The risk would be the integral of the probabilities of facing adverse climatic conditions, times the expected consequences. If a warning is made, it can be interpreted as a deviation from average conditions (in the case of drought, it would mean a shift from average to drier climate). This would increase the probability of facing climatic conditions beyond the coping capacity and the expected value of damages. When the expected value of damages exceeds a given threshold, a decision may be made to take some management actions to react to the increased risk.

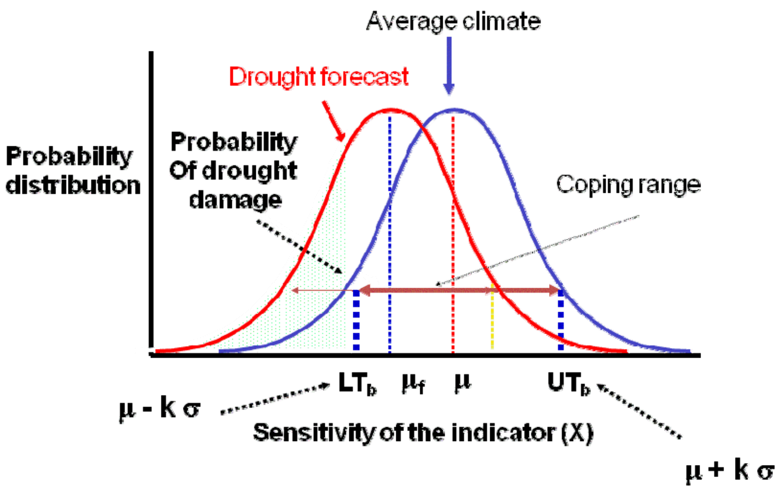


Figure 2 Calculation of drought risk when probabilities information is available

Many drought indicators have been developed in the past decennia, a number of popular indicators are the Standardized Precipitation Index, Palmer Drought Severity Index, Palmer Hydrologic Drought Index, Moisture Adequacy Index, and social indicators (See Deliverable 3.1).

To assess the impact of drought on vulnerable regions and to translate a drought forecasts into warnings, here we evaluate which water resources specific sectors rely and the spatial variability herein.

4. GLOBAL PUBLICLY AVAILABLE DATASETS

Table 1 describes the publicly available datasets that may characterise different aspects of drought vulnerability -- ranging from demographics and socioeconomics to natural resources and climate – that are related to drought vulnerability.

Table 1 Summary of the global publicly available datasets with variables related to drought vulnerability

Num	Indicators or Variables	Description and source of data
V 1.	Water resources (many variables)	WWDRII Global water resources (many variables, very comprehensive database, the best database, including an African Study) World Water Development Report II (WWDRII) developed by the Water Systems Analysis Group of the University of New Hampshire (UNH), USA, describing the current status of global water resources and associated human interactions and pressures. http://wwdrii.sr.unh.edu
V 2.	Water withdrawals and consumption	Pacific institute: World water database maintained by the Pacific Institute, USA, www.worldwater.org
V 3.	Water and agricultural database	AQUASTAT is a global database on water and agriculture, country level http://www.fao.org/nr/water/aquastat/data/query/index.html
V 4.	Precipitation	Gridded precipitation dataset (CRU TS 2.0) Mitchell TD, Carter TR, Jones PD, Hulme M, New M (2004) A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Tyndall Centre for Climate Change Research Working Paper 55 (July 2004)
V 5.	Precipitation projections for the 21 century	Burke EJ, Brown SJ, Christidis N (2006) Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model Evolution of climatological drought. Journal of Hydrometeorology, 7,
V 6.	Hazard (PDSI)	Global Dataset of Palmer Drought Severity Index Dai A, Trenberth KE, Qian T (2004) A Global Dataset of Palmer Drought Severity Index for 1870–2002: Relationship with Soil Moisture and Effects of Surface Warming, Journal of Hydrometeorology, 5, 1117-1130
V 7.	Runoff	Annual runoff (mm/year per grid cell) – a 0.5o resolution global gridded dataset of long-term average (1950-2000) annual runoff per grid cell computed by Water Balance Model (WBM) Vorosmarty et al. 1998
V 8.	Streamflow	Dettinger MD, Diaz HR (2000) Global Characteristics of Stream Flow Seasonality and Variability. J. Hydrometeor, 1, 289–310
V 9.	Groundwater	Groundwater (several papers but not in database format) http://wri.wisc.edu/Default.aspx?tabid=79
V 10.	Water	Earthtrends Searchable Database (earthtrends.wri.org/index.php) maintained by the World Resources Institute (WRI), USA http://www.wri.org/project/earthtrends/
V 11.	Water policy	the State of Water database (www.wepa-db.net/policies/top.htm) maintained by the Water Environment Partnership in Asia (WEPA), Japan. Legislative framework

Num	Indicators or Variables	Description and source of data
V 12.	Dams, lakes and reservoirs	International Commission on Large Dams (ICOLD) World Register of Dams compiled by the International Commission on Large Dams (ICOLD) (www.icold-cigb.net/) is a reference to large dams (height - greater than or equal to 15 meters (m)) of the world providing information such as dam type, height, capacity and purpose www.icold-cigb.org
V 13.	Index of Water Infrastructure	Infrastructure vulnerability index: IWMI 2009 Eriyagama, Nishadi; Smakhtin, Vladimir; Gamage, Nilantha. 2009. Mapping drought patterns and impacts: a global perspective. Colombo, Sri Lanka: International Water Management Institute (IWMI). 23p. (IWMI Research Report 133) doi: 10.3910/2009.132 http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB133/RR133.aspx
V 14.	Soils production index	FAO digital media series: soils of the world http://www.fao.org/nr/land/soils/en/
V 15.	Soil degradation	Global assessment of human induced soil degradation GLASOD project of the International Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands (commissioned by the UNEP), http://www.isric.org/data/global-assessment-human-induced-soil-degradation-glasod
V 16.	Population	Global gridded population Gridded Population of the World, version 3 (GPWv3) The Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University, USA www.sedac.ciesin.Columbia.edu.gpw
V 17.	Vulnerability (observed impacts)	Observations of 807 drought episodes reviewed Below R, Gorver-Kopec E, Dilley M (2007) Documenting Drought-Related Disasters: A Global Reassessment, The Journal of Environment Development, 16(3), 328-344
V 18.	Hotspots	Natural disaster hotspots, project of the World Bank. Dilley M, Chen RS, Deichmann U, Lerner-Lam AL (2000) Natural Disaster Hotspots: A Global Risk Analysis, Disaster Risk Management 5
V 19.	Water poverty index	Water wealth index Sullivan CA (2002) Calculating a Water Poverty Index. World Development, 30, 1195–1210
V 20.	Climate change	UNEP 2008: Atlas of our changing environment AFRICA Atlas of Our Changing Environment http://www.unep.org/dewa/africa/africaAtlas/PDF/en/Africa_Atlas_Full_en.pdf
V 21.	Land use	Global land use dataset http://www.sage.wisc.edu/iamdata/
V 22.	Land use	Global Land Use Dataset (www.sage.wisc.edu/iamdata/) held by the Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Madison, USA, describe the geographic patterns of the world's croplands, grazing lands, urban areas, and natural vegetation. Data sources are Ramankutty and Foley 1998.
V 23.	Agricultural water scarcity	Chronic agricultural water scarcity: Falkenmark 1989 Falkenmark M (1989) The Massive Water Scarcity Now Threatening Africa: Why Isn't It Being Addressed?. Ambio, 18(2), 112-118 http://www.jstor.org/stable/4313541
V 24.	Agriculture	ProdSTAT (faostat.fao.org/site/526/default. aspx) maintained by the FAO contains detailed agricultural production data, area/stock and yield data on a country basis starting from 1961
V 25.	Infrastructure	Infrastructure Vulnerability Index (IMWI, 2009)

Num	Indicators or Variables	Description and source of data
V 26.	Development	World Development Indicators (WDI) (www.worldbank.org/) is the World Bank's premier annual compilation of data about development. It includes some 800 indicators (in 2008) on economic output, welfare, status of the environment and the quality of governance - for some 209 (in 2008) countries in the world. http://data.worldbank.org/data-catalog/world-development-indicators/wdi-2010
V 27.	Socioeconomic	Socio-economic drought vulnerability index IWMI 2010 Eriyagama N, Smakhtin V, Gamage N (2009) Mapping drought patterns and impacts: a global perspective. Colombo, Sri Lanka: International Water Management Institute (IWMI). 23p. (IWMI Research Report 133) doi: 10.3910/2009.132 http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB133/RR133.aspx
V 28.	Socioeconomic	Iglesias et al., 2010 for Mediterranean countries, This deliverable global assessment

5. CONTINENTAL VULNERABILITY

The vulnerability evaluation at the pan-African level, aims to developing a pre-operational drought forecasting system, and mitigating the effect of drought on food security and water availability predictions across the continent.

Many indices and their thresholds have been applied at large scale (for instance the 5% probability of nonexceedance of flow) and used to determine variability of water stress in time.

Vulnerability in Africa depends for instance on access to local water resources and the ability to use them, and several socioeconomic circumstances such as employment opportunities, available household capital and market access (Eriksen & Silva, 2009). Agriculture is a very specific water user of which also other external factors determine drought vulnerability such as soil properties (Slegers, 2008), tillage practices (Temesgen et al., 2008;Makurira et al., 2008) and the ability to supplement rain fed agriculture by irrigation (Eriksen & Silva, 2009).

The underlying causes of risk may be related to structural problems, such as lack of adequate hydraulic infrastructures or technology, and also to management, economic and social features that increase the vulnerability of the region, watershed or water supply system under analysis. For example, the direct impact of precipitation deficiencies may be a reduction of crop yields. The underlying cause of this vulnerability, however, may be that the farmers did not use drought- resistant seeds, either because they did not have access to the information; their costs were too high, or other causes.

Another example could be farm foreclosure related to drought. The underlying cause of this vulnerability could be many things, such as small farm size because of historical land appropriation policies, lack of credit for diversification options, farming on marginal lands, limited knowledge of possible farming options, a lack of local industry for off-farm supplemental income, or government policies.

The selection of vulnerability indicators was made with the following criteria: require only existing and readily available data; are easy to interpret; be appropriate to represent some aspect of vulnerability; discriminate to a reasonable degree between different levels of intensity; and be valid, the results being reasonable predictors of the results of more detailed studies.

There are two key challenges in the design of a vulnerability index that is an adequate representation of the cause-effects relationship between drought and its impacts. First, the selection of the variables to be included, and second, the weighting of each variable. These two questions are ideally answered in the context of decision-oriented stakeholder and expert dialogues. Here we present a vulnerability index that includes a very large set of important variables from the theoretical point of view. The stakeholders in the case studies should select the most adequate variables and their weighting in each case.

All maps have been elaborated for this report by the authors with the publicly available datasets described above.

5.1 DROUGHT HAZARD INDICATORS

Precipitation and the derived analytical variables is the main indicator that characterise drought (Figure 3). More information is provide in the Deliverables of WP4. In the annex, a series of maps are presented that provide information on the main variables that define vulnerability to drought.

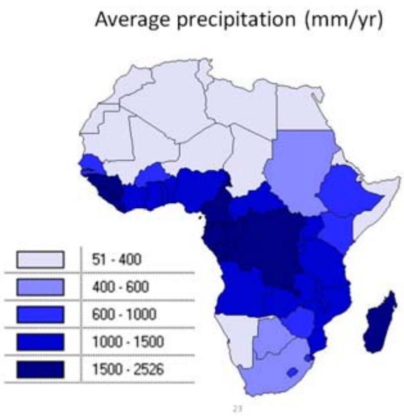


Figure 3 Average precipitation

5.2 EARTH OBSERVATION INDICATORS

Horion et al (2010) analysed the potential contribution of combining meteorological and remote sensing based indicators. Vicente-Serrano et al (2012) analysed the potential use of geospatial data and drought information systems in Africa. Rojas et al (2011) proposed a novel method for calculating the empirical probability of having a significant proportion of the total agricultural area affected by drought at sub-national level. The assessment is based on the Vegetation Health Index (VHI) from the Advanced Very High Resolution Radiometer (AVHRR) averaged over the crop season as main drought indicator., a phenological model based on NDVI was employed for defining the start of season (SOS) and end of the grain filling stage (GFS) dates. Second, the per-pixel average VHI was aggregated for agricultural areas at sub-national level in order to obtain a drought intensity indicator. Seasonal VHI averaging according to the phenological model proved to be a valid drought indicator for the African continent, and is highly correlated with the drought events recorded during the period (1981–2009). The final results express the empirical probability of drought occurrence over both the temporal and the spatial domain, representing a promising tool for future drought monitoring.

In the context of D2.1 there is no possibility of including this very valuable indicator in the mapping. The Annex provides examples of using EOS indicators.

5.3 WATER RESOURCES AND WATER INFRASTRUCUTURE INDICATORS

Vulnerability in water supply and irrigated systems is directly related to water scarcity, which differs from drought because it is related to a shortage of water availability to satisfy demands. The shortage results from an unbalance between water supply and demand, which is originated by a meteorological phenomenon, but is also conditioned by other time-varying factors, such as demand development, supply infrastructure and management strategies. The result of the unbalance is demand deficit, which is of concern for water managers. It is usually anti-economical to guarantee 100% all demands in a system, and a risk level has to be adopted in the risk management plan. Theoretical models are used to characterise risk in hydrological systems (Rossi et al., 2003). The acceptable risk level is conditioned by available water resources and infrastructure and depends on demand characteristics and their elasticity.

The ability of various countries to satisfy their water needs during drought conditions is examined using storage-related indices.

The balance between water demand and availability has reached a critical level in many areas of Africa (water scarcity). In addition, more and more areas are adversely affected by changes in the hydrological cycle and precipitation patterns (increasing aridity and frequency of droughts). Climate change will almost certainly exacerbate these adverse impacts in the future, with more frequent and severe droughts expected across Africa.

Groundwater is a strategic water supply source in Africa (e.g., Egypt), and its strategic value becomes more relevant during drought conditions. Only prolonged meteorological droughts have and effect on groundwater levels. Critical level of groundwater can be derived from the minimum threshold levels associated with no impacts.

The distribution of resources in a drought period among multiple demands in hydrological systems is a challenging task requiring careful planning. The operational rules of the system are related to resource sharing criteria, priorities among users, utilization of complementary resources and strategic reserves among others. In large systems, mathematical simulation and optimisation models should be used to obtain quantitative results accounting for all system complexities in an uncertain context. These models provide guidance in identifying critical demands, evaluating the effect of capacity building or water conservation measures, and scheduling available actions within given constraints. All models provide a measure of demands reliability, quantified as the probability that a given demand may suffer water shortages during a given drought.

However, the availability of well-calibrated operational models is doubtful in some parts of the DEWFORA target area. They require a large investment in information, to evaluate resources, characterise demands, identify optimal management criteria, etc, which may not be readily available in all regions. If these models are available, they should be used in risk analysis, using indicators derived from model results to evaluate relative risks. If they are not, it can be assumed that the system is not very complex, and risk analysis can be carried out with simpler indicators.

Water resources indicators are presented in Figure 4 and the infrastructure indicators are presented in Figure 5. It is important to notice that regulation of water in Africa is extremely low (1267 dams compared with 47665 dams in the world). The storage as proportion of total annual renewable water resources (Figure 6) and storage-drought duration Index (Figure 7) provide analytical information about the role of infrastructure in drought vulnerability.

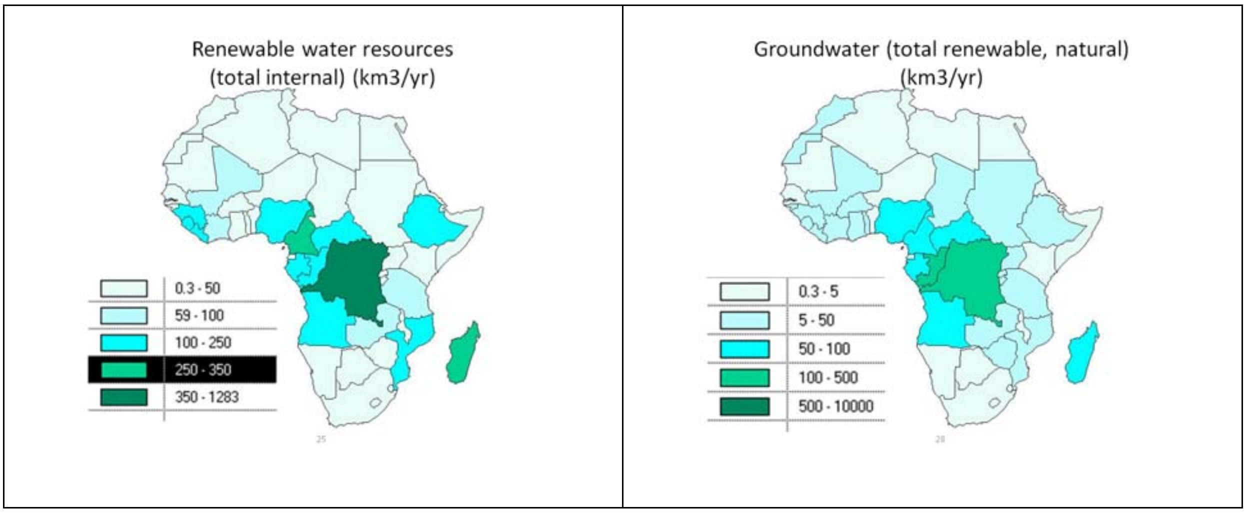


Figure 4 Renewable water resources and groundwater resources

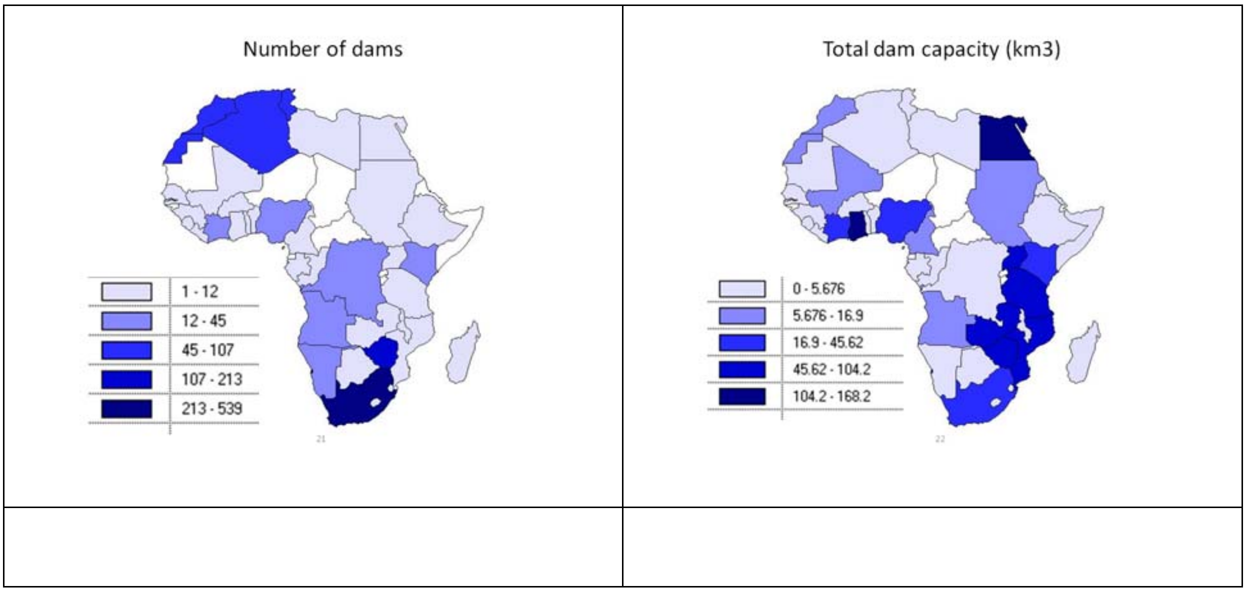


Figure 5 Water resources infrastructure

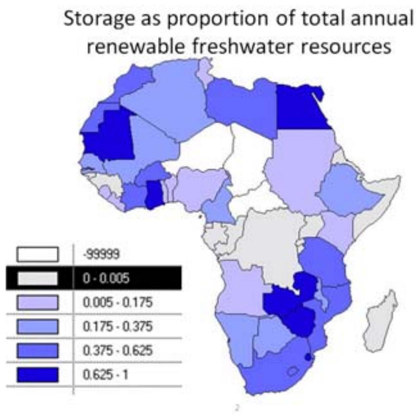


Figure 6 Storage as proportion of total annual renewable water resources.

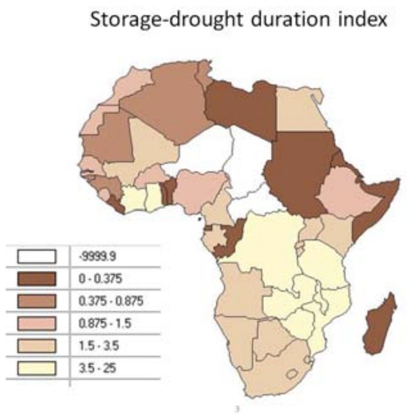


Figure 7 Storage-drought duration Index Based on IMWI datasets

5.4 AGRICULTURE

Given the importance of agriculture in the chain of drought impacts and the livelihoods in many areas, we have selected several agricultural indicators that are presented in Figure 8, Figure 9 and Figure 10.

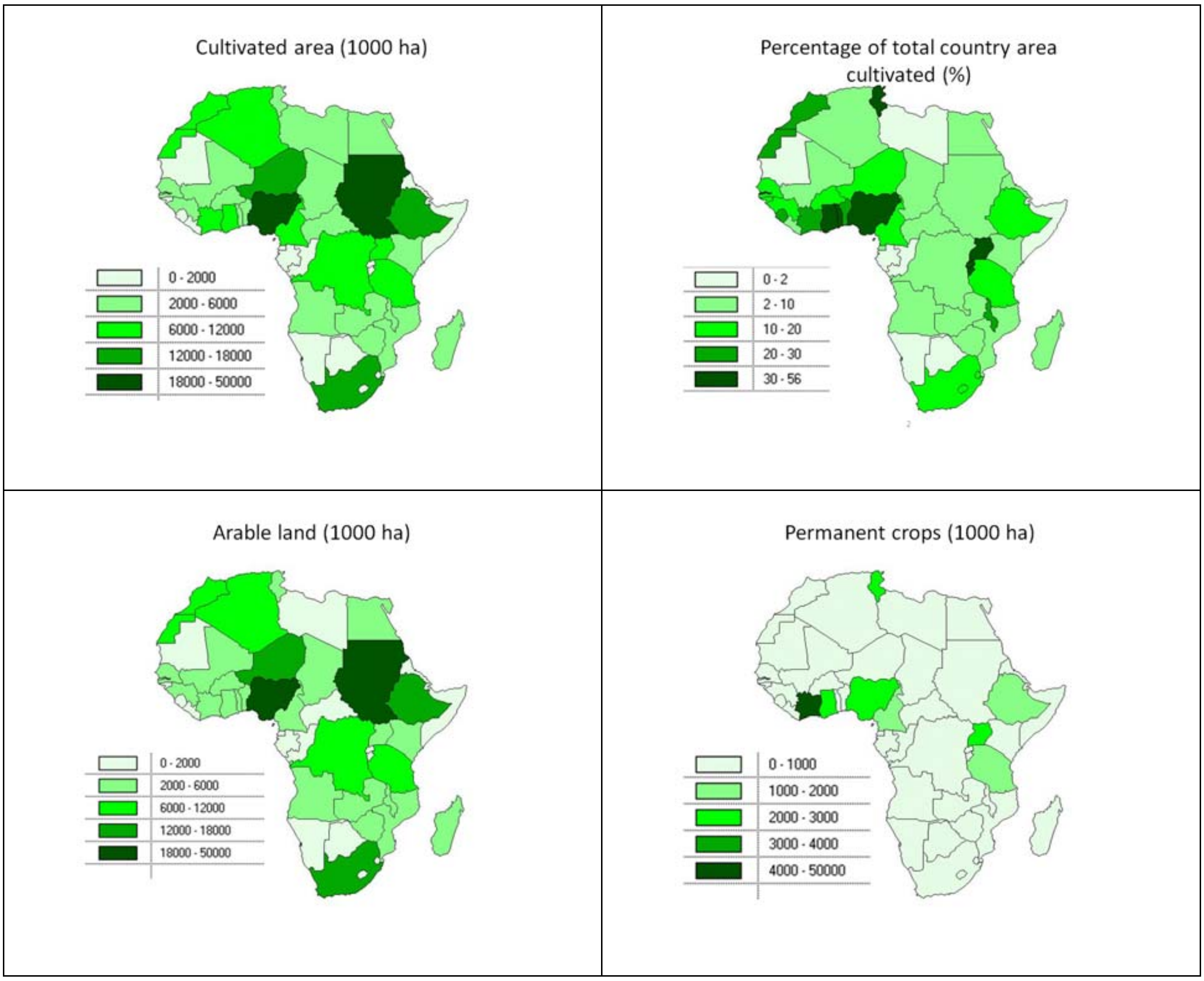


Figure 8 Agricultural indicators

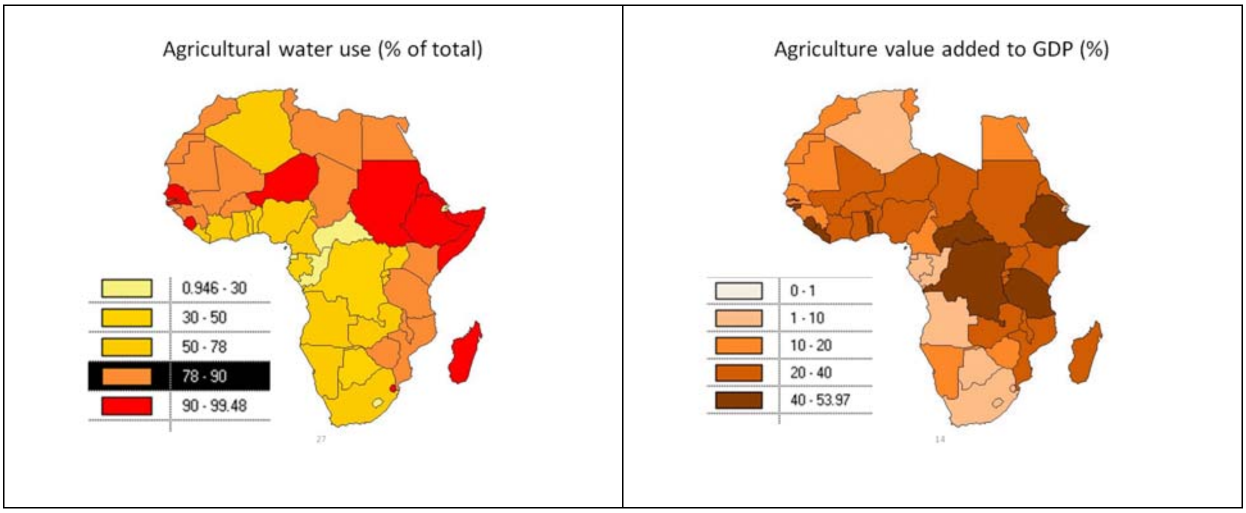


Figure 9 Agricultural indicators: water use and value added

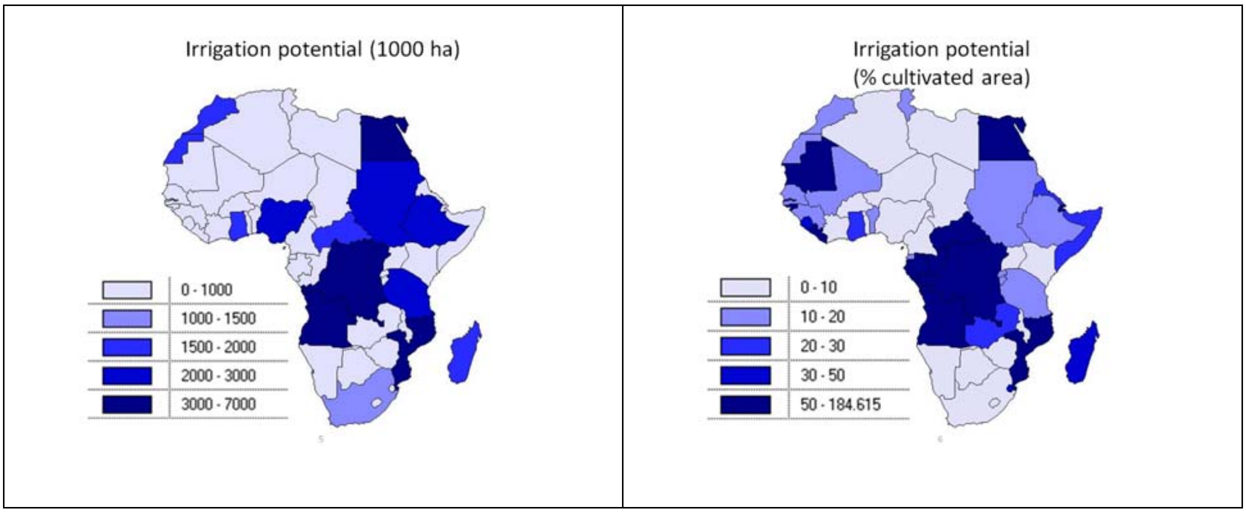


Figure 10 Irrigation potential and share of irrigated cultivated land

5.5 POPULATION

Population is defines exposure and demographic indicators are important compoenetn of a vulnerability assessment, the distribution of population potentially exposed in shown in Figure 11 and the economically active population in Figure 12.

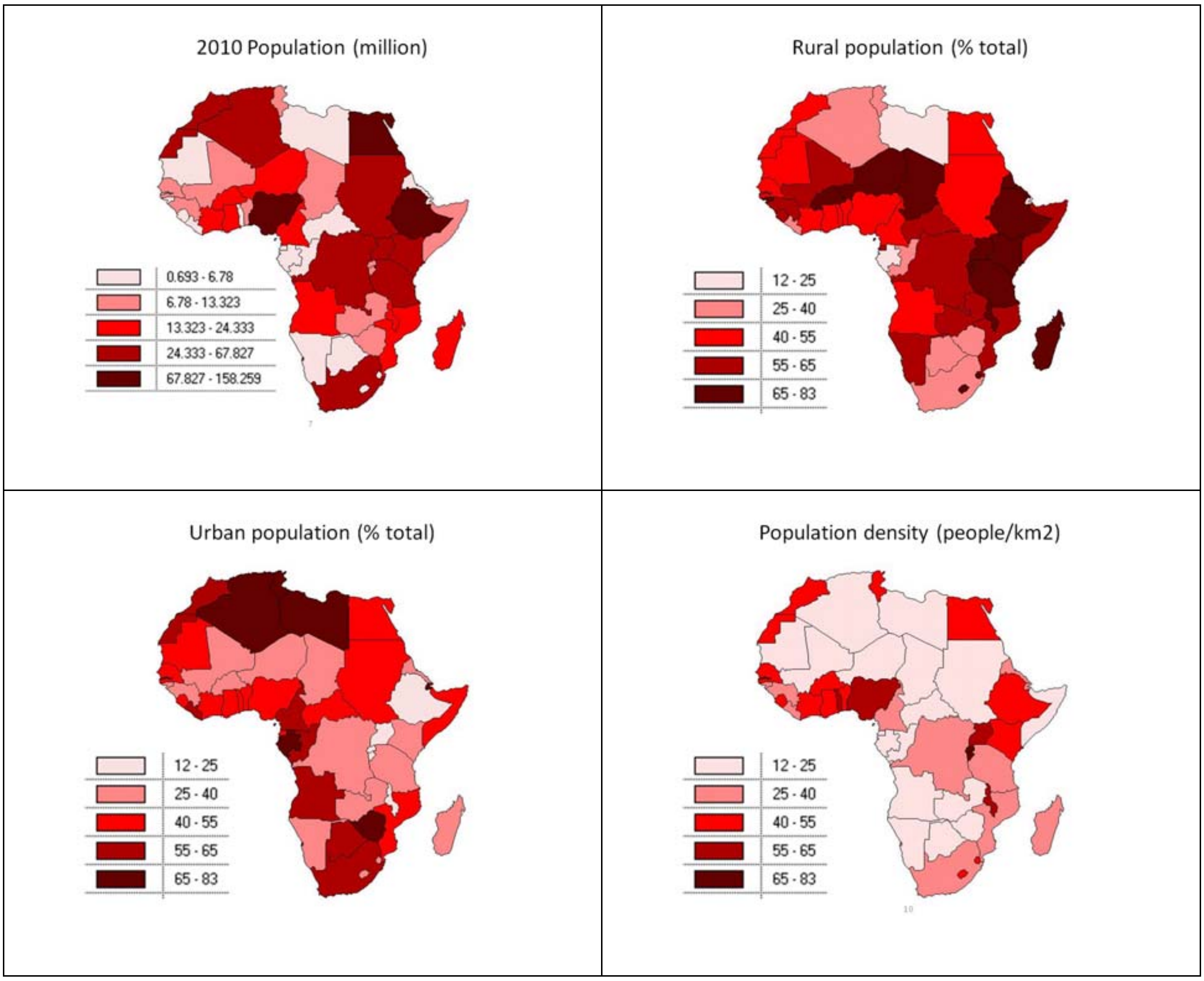


Figure 11 Total population (2000)

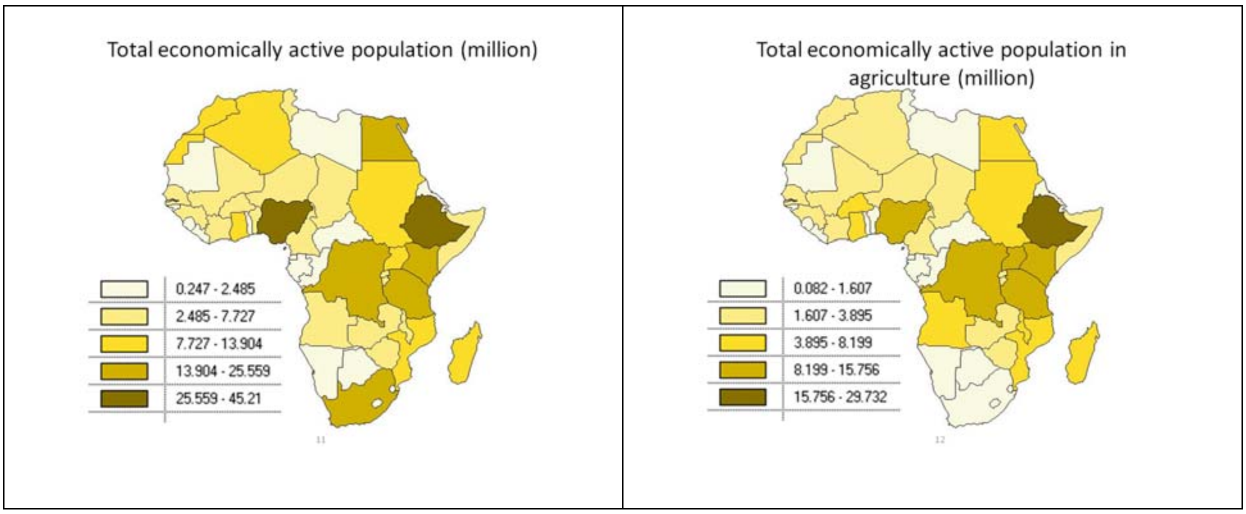


Figure 12 Economically active population

5.6 DEVELOPMENT INDICATORS

Among the most crucial development indicators are access to water and sanitation of the population (Figure 13) An example of the analysis between human development and access to water is shown in Figure 14.

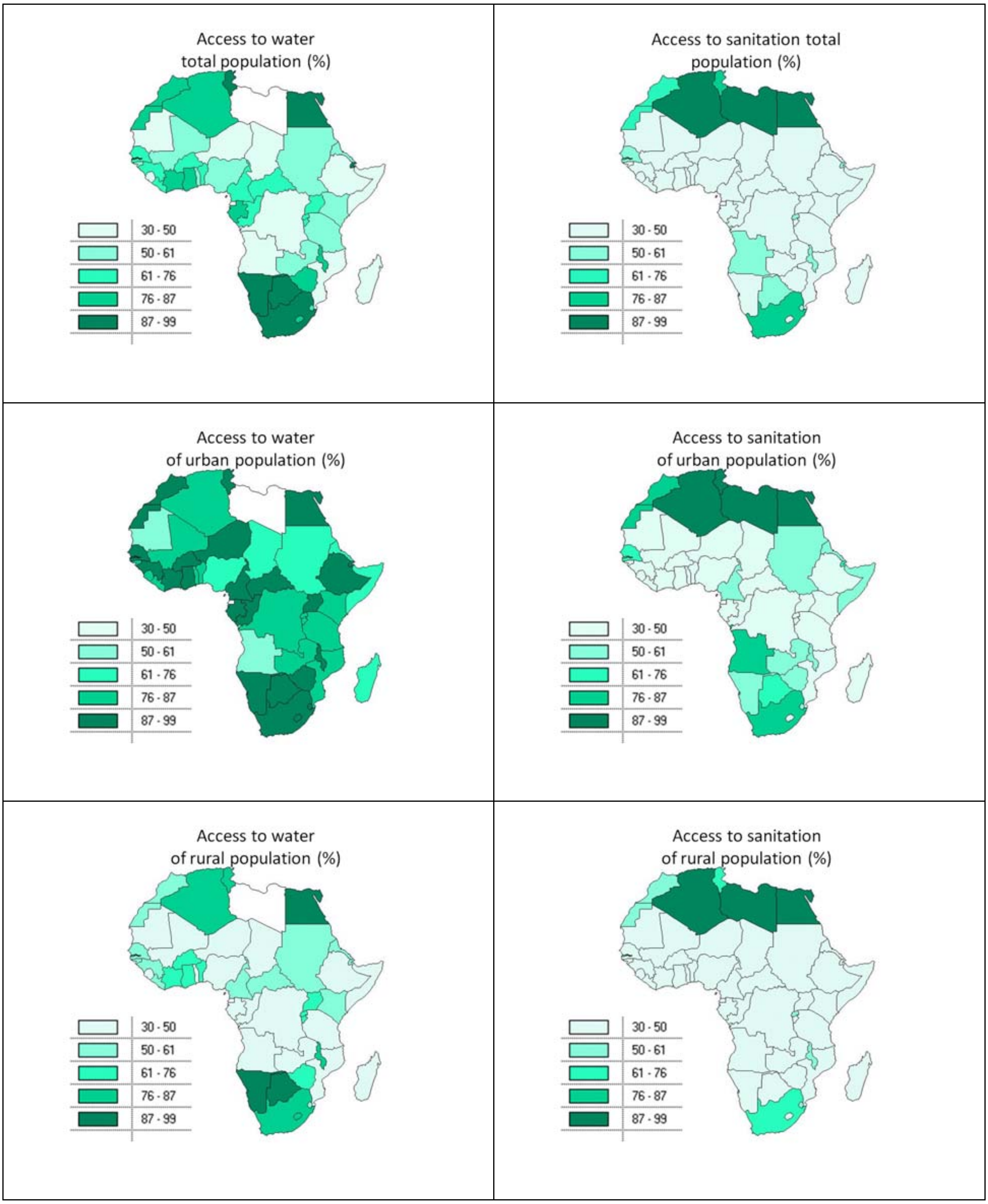


Figure 13 Access to water and sanitation

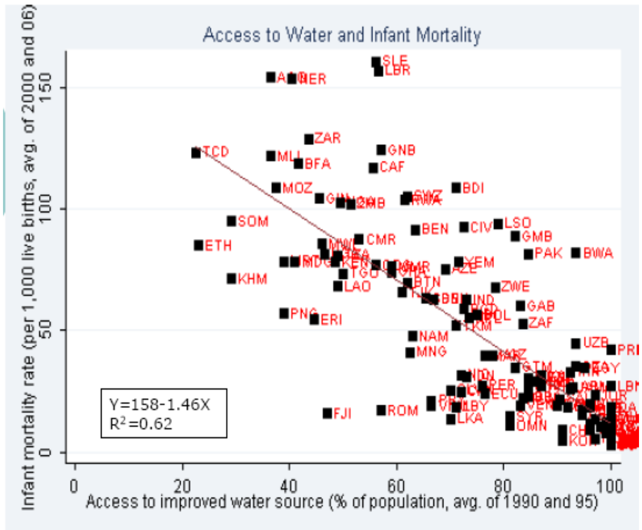


Figure 14 Correlation between infrastructure and population health. Source : Serven, 2008 (the World Bank)

The infrastructure vulnerability index is based on the percentage of people having access to an improved water source and general accessibility of rural areas through the road network (Figure 15).

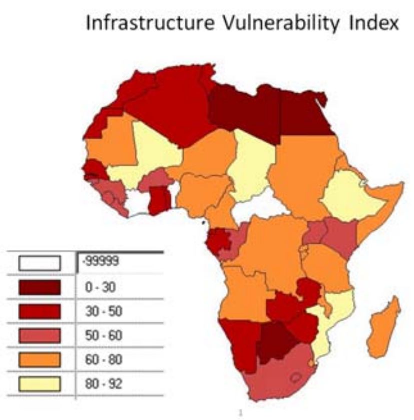


Figure 15 Infrastructure Vulnerability Index

The Human Development Index and the access to water resources based on UN data in Figure 16.

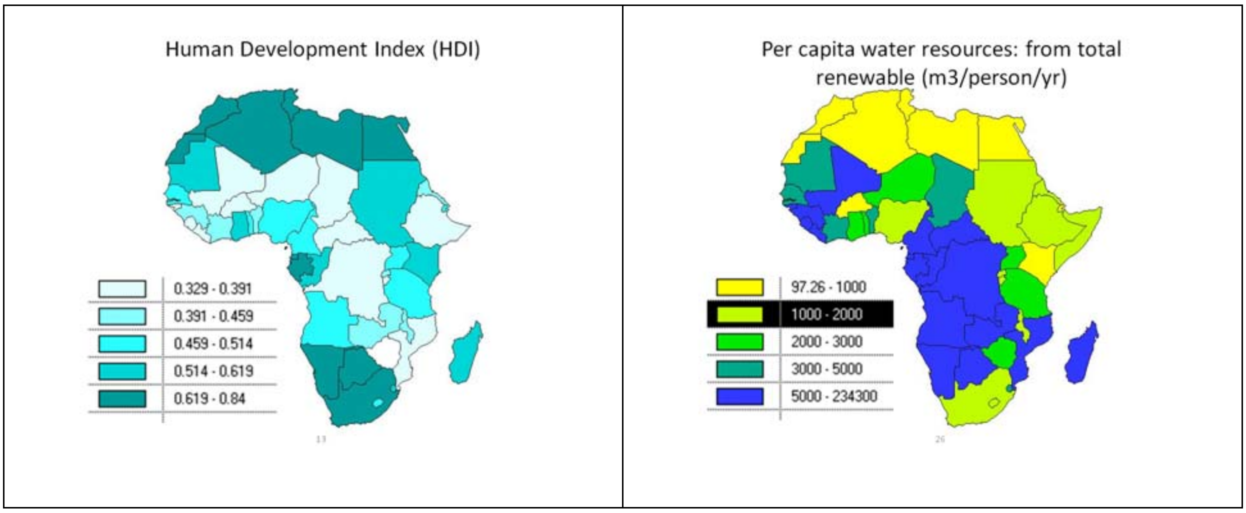


Figure 16 Human development index and per capita water resources

5.7 A DROUGHT VULNERABILITY INDEX

Social vulnerability to drought is complex but is reflected by the social capacity to anticipate, cope with and respond to drought. Here we estimate these aspects of social vulnerability evaluating the natural resource structure, the economic capacity, the human and civic resources, and aspects of agricultural innovation. The weight is each component of the index is a key determinant of the final value. Here we Here we present the results of the index under two valuation scenarios. In Scenario 1 all components are valued equally. In Scenario 2 the human resources component is given 50% of the weight, the economic and natural resource components are given 20% of the weight each, and the agricultural technology is given 10% if the weight. This reflects the assumption that a society with institutional coordination and strengths for public participation is less vulnerable to drought and that agriculture is only one of the sectors affected by drought. The vulnerability index establishes robust conclusions since the range of values across countries does not change with the assumptions under the two scenarios.

An index that estimates social vulnerability to drought is developed and calculated in all countries in Africa. The methodology is appropriate to integrate both quantitative and qualitative characterisations of vulnerability -- this permits the involvement of the stakeholders in the process. The index can be applied locally or spatially and with different aggregation levels of the input data. The intermediate components can be evaluated independently, allowing comprehensive interpretation of the strengths and weaknesses of each system.

The sequential steps taken for the quantification of the vulnerability index are: (a) select proxy variables for factors that contribute to the vulnerability; (b) normalize the proxy variables with respect to some common baseline; (c) combine the sub-component proxy variables within each vulnerability category by weighted averages; and (d) quantify vulnerability as the weighted average of the components.

SELECTION OF VARIABLES

The socio-economic vulnerability components (Table 2) and the variables included were selected because: (1) data is readily available and an example may be computed to assist stakeholders in defining the sensitivity of the system; and (2) the variables are drought scenario dependent and geographically explicit. The vulnerability index may be used to understand the sensitivity of the system and to assist in the selection of measures to be adopted. For example, improving the efficiency of agricultural water use, decreasing population under the poverty line, increasing adult literacy rate, and increasing agricultural technology, are measures that result in an overall vulnerability decrease.

The components of socio-economic vulnerability and the representative variables that have been used to characterise it are provided in Table 1. A final indicator for each category of exposure may be computed as the weighted average of all the representative variables within the category.

Table 2 Components of socio-economic vulnerability and representative variables that can be used to characterise the vulnerable groups

Components	Aspect relevant to adaptive capacity	Variables
Social and Civic Resources capital	Human development (individual level)	Adult literacy rate Life expectancy
	Collective capacity	Agricultural GDP Population without access to improved water Population below the poverty line
	Institutional coordination	Institutional relations Public participation
	Pressure on resources	Total population Human and civic resources Agricultural employment (% of total) Adult literacy rate (% of total) Life expectancy at birth (years) Population without access to improved water (% of total)

Economic capital	Economic welfare	GDP per capita Energy use
	Public intervention	Public expenditure GDP millions US$ GDP per capita US$ Agricultural value added/GDP % Energy use (kg oil equivalent per capita) Population below poverty line (% population with less that 1 US$/day)
Infrastructure and Technological capital	Eco-efficiency	GDP per unit energy use High technology exports CO2 emissions per capita Regulation and management of water resources Infrastructure index
	Agricultural innovation	Fertilizer consumption Fertiliser consumption (100 gr/ha of arable land) Agricultural machinery (tractors per 100 km2 of arable land)
Renewable Natural capital	Water management	Total water use Agricultural water use Irrigated area
	Environmental damage	Area salinised by irrigation Agricultural water use (%) Total water use(% of renewable) Average precipitation 61-90 (mm/year) Area salinised by irrigation (ha) Irrigated area (% of cropland) Population density

COMPUTING THE DROUGHT VULNERABILITY INDEX

The selected variables were normalized between the different countries in order to compare the results. The standarization has been made with respect the maximum value of each variable across the countries to combine within the categories and guarantee the index being a percent rate. Combine the sub-component proxy variables within each category by using either a geometric mean (MOSS et al., 2000) or a weighted mean with weights inversely proportional to the impact uncertainty level

Sub-component proxy variables can be combined within each category by using either a geometric mean or a weighted mean with weights inversely proportional to the impact uncertainty level. This study considers the weights separately for each of the categories, as in Iglesias et al (2007), in order to evaluate them independently, allowing noticing the strengths and weaknesses of each component of the total vulnerability index within each country. Should be noticed that the vulnerability components have inverse interpretation that adaptation capacity ones.

The total vulnerability index has been quantified as the weighted average of each of the components. The scores of the vulnerability index range on a scale of 0 to 1, being 0 the least vulnerable and 1 the most vulnerable. The total index is generated as the average of all components. The final value of the index depends on the valuation of each component. Here we present the results of the index under the assumptions that all components are weighted equally. This reflects the assumption that a society with institutional coordination and strengths for public participation may play a very important role in drought mitigation.

The figures below show the vulnerability of the different natural resource capital Figure 17), the economic capital (Figure 18), the human and civic resources capital (Figure 19), the infrastructure and technological capital (Figure 20) and the overall drought vulnerability index (Figure 21).

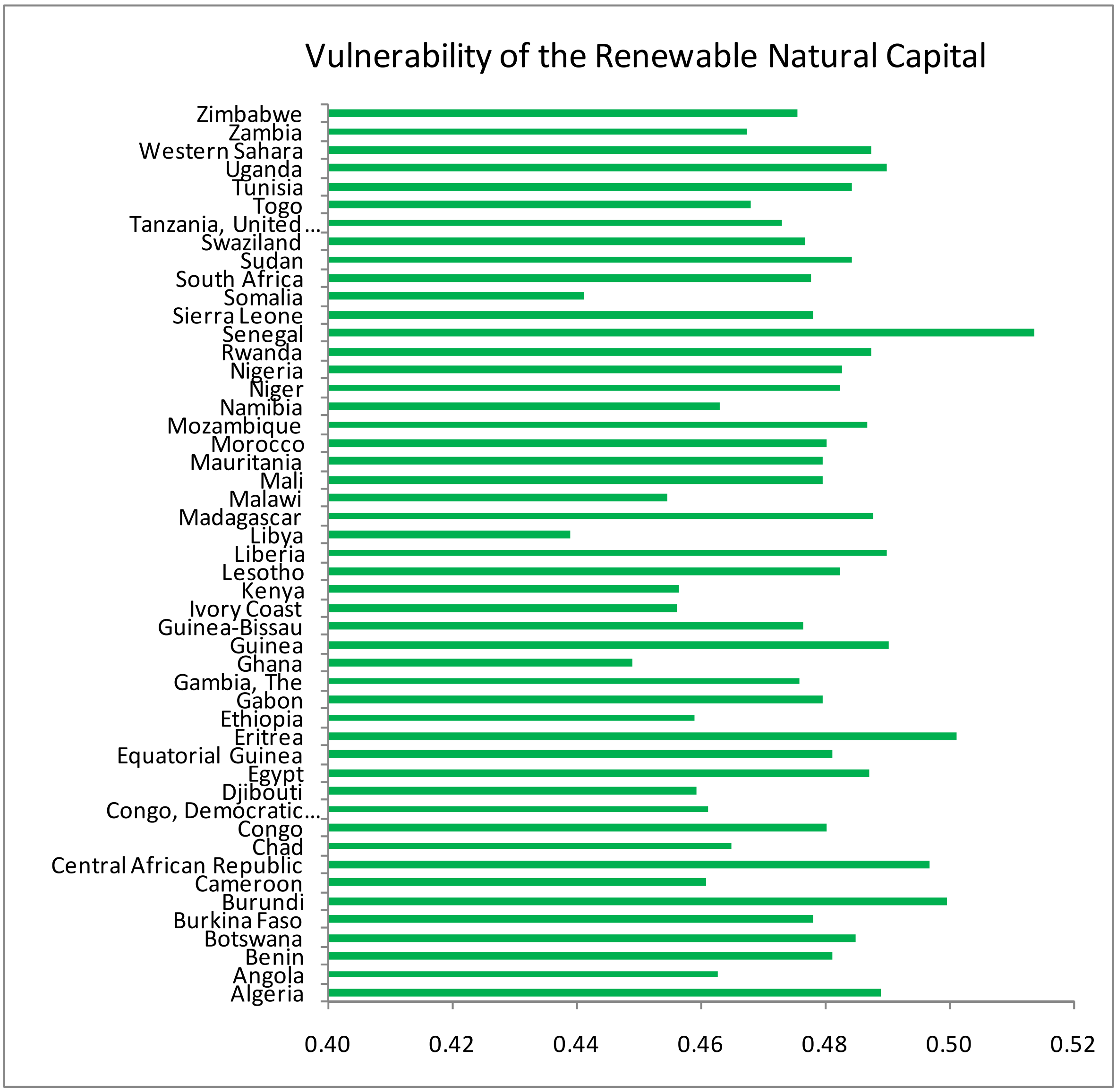


Figure 17 Vulnerability of the renewable natural capital

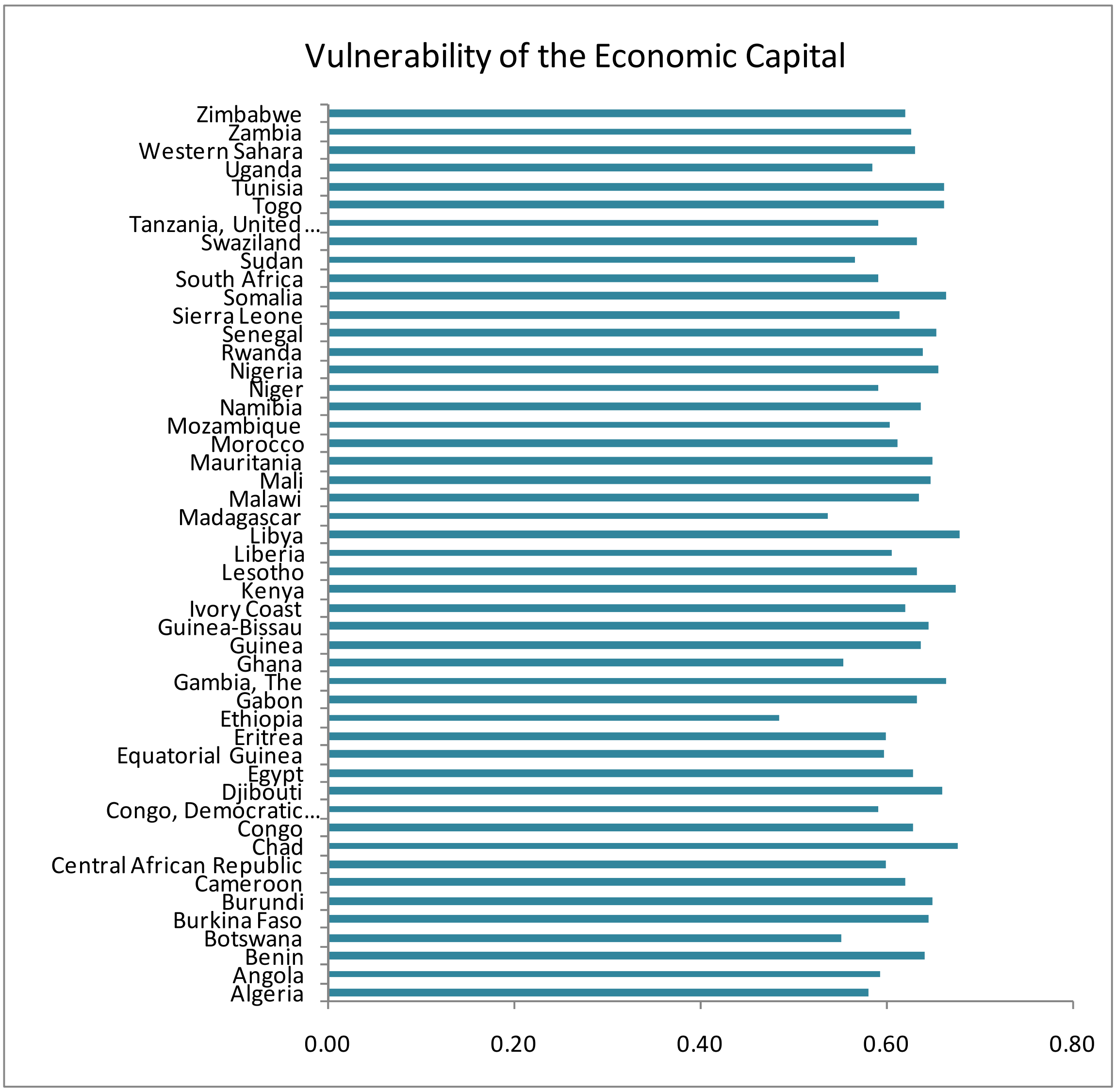


Figure 18 Vulnerability of the economic capital

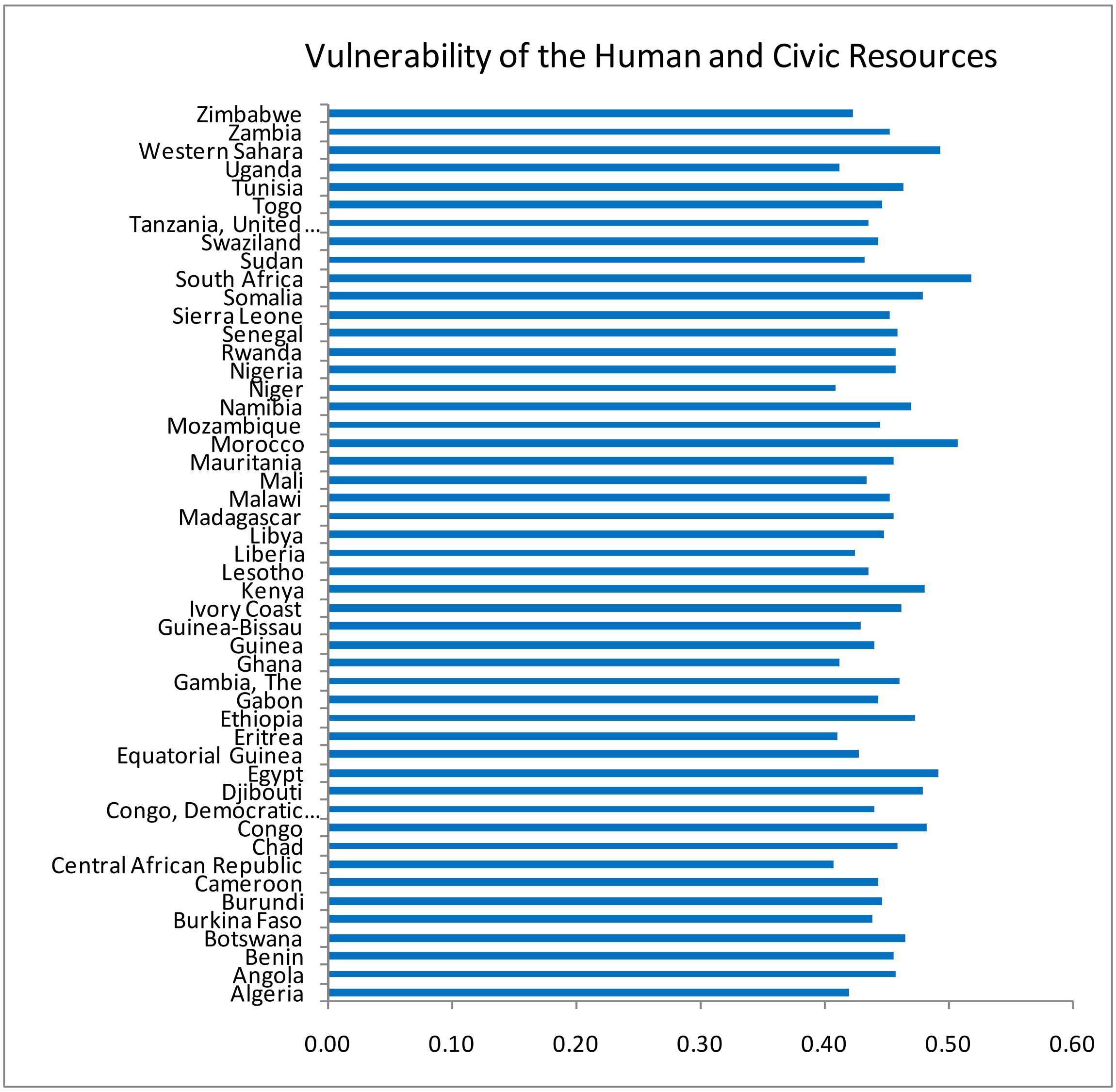


Figure 19 Vulnerability of the human and civic resources

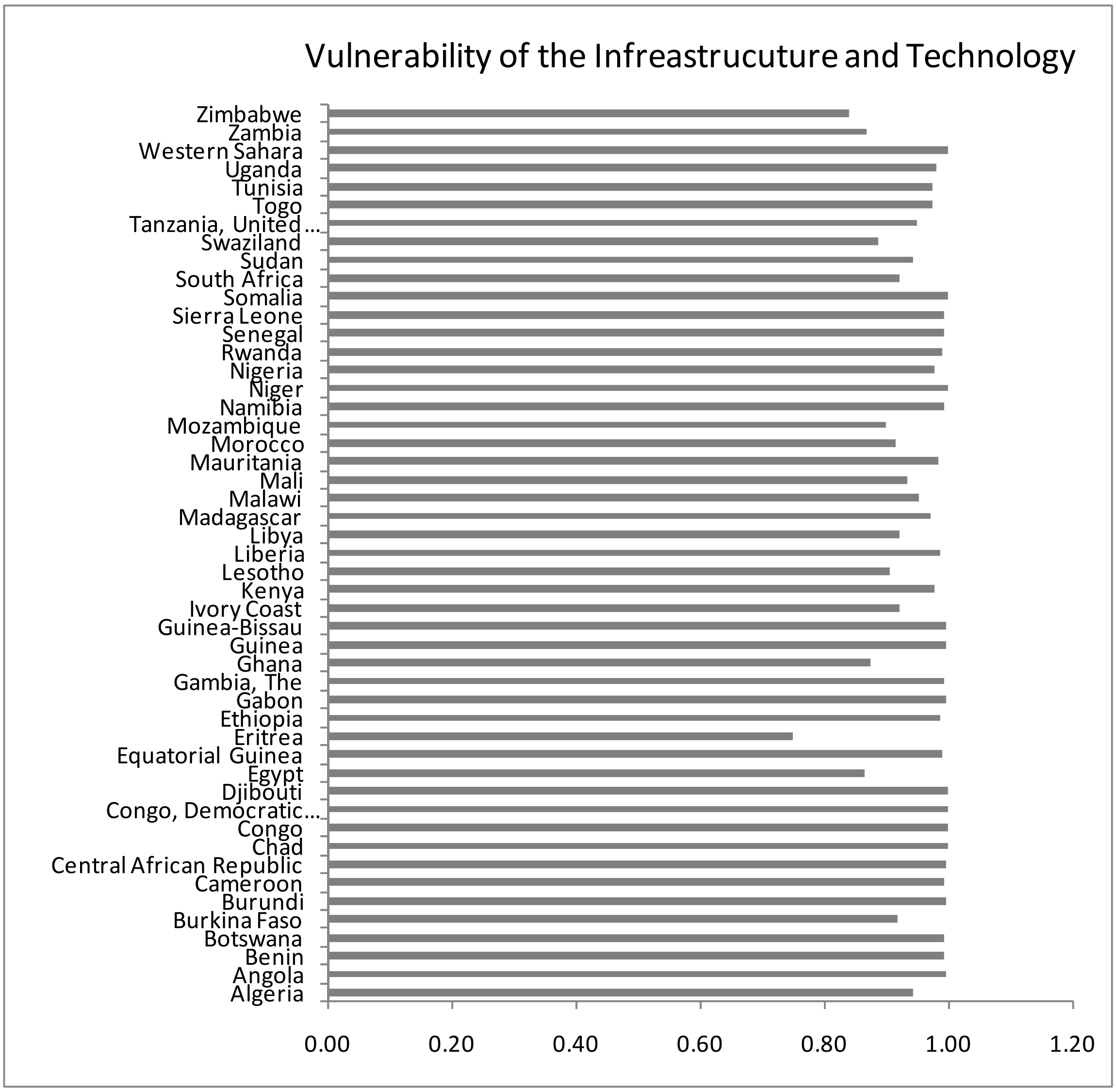


Figure 20 Vulnerability of the infrastructure and technological capital

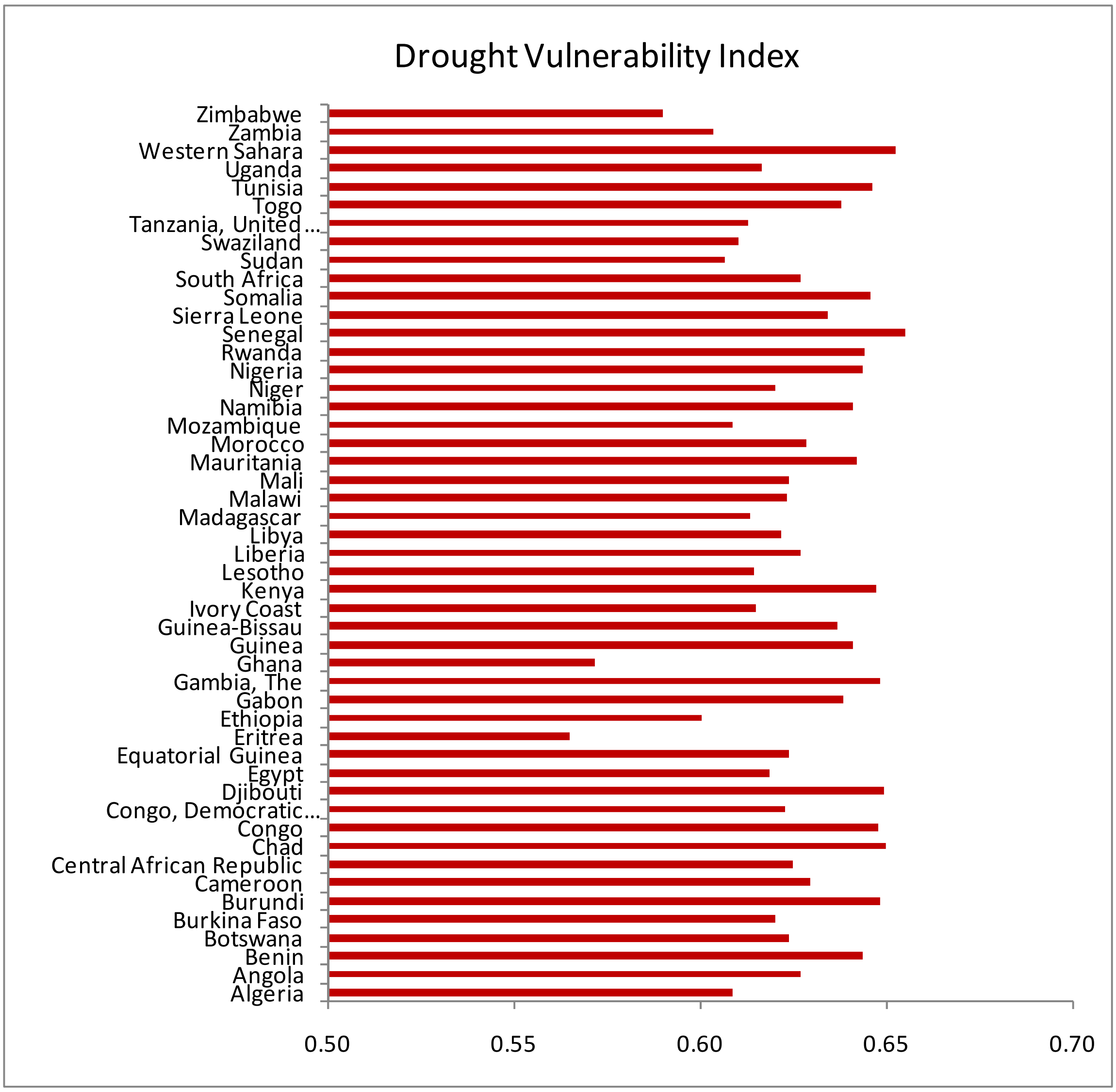


Figure 21 Drought Vulnerability Index

5.8 POLICY RELEVANCE OF THE SELECTED INDICATORS

The results of this evaluation lead to the identification of actions to minimize risk by reducing the underlying causes (vulnerability). The results contribute to increase the adaptive capacity and develop policy decisions to increase adaptation options. The vulnerability assessment bridges the gap between impact assessment and policy formulation by directing policy attention to underlying causes of vulnerability rather than to its result, the negative impacts, which follow triggering events such as drought (Wilhite, 2005). The vulnerability evaluation helps defining the sensitivity of the systems to external shocks and identifying the most relevant aspect that decrease the level of risk.

Ideally, the sets of indicator values may define vulnerability thresholds. Defining critical thresholds is very complex. A threshold is the value at which action is initiated – and not necessarily that at which problems occur. In some literature this leads to two types of threshold – the one is called an action or operational threshold, the other a result threshold.

Vulnerability indices help to identify and target vulnerable regions or populations, raise awareness, and form part of a monitoring and adaptation strategy.

The indicators selected include characterisation of the drought natural event, water resources indicators, water infrastructure and management, and socio-economic indicators. The socio-economic indicators include adult literacy, life expectancy at birth, population without access to improved water, and GDP, that are among the most favoured indicators of sustainable development, and are used as components of United Nations Development Programme's (UNDP) Human Development Index. The policy-relevance of the groups of indicators and the individual indicators selected is presented below.

SOCIAL CAPACITY. Social characteristics depend to a large extent on the type of policies implemented in the country or region, ranging from self-sufficiency strategies based on market or protective policies for industrialized nations where agriculture might only play a marginal role. This component can be represented through some general variables like agricultural employment, which has a negative correlation to the overall adaptive capacity because it implies a greater dependency of society on a highly variable sector. Other variables associated to this component are literacy rate, life expectancy or access to sanitized water, all of them positively correlated to adaptive capacity because they imply healthier and stronger societies that can develop and implement solutions to adapt to drought in a more efficient manner. The evaluation of the effectiveness of institutional interaction and response are determinant for the implementation of potential adaptive capacity to drought.

ECONOMIC CAPACITY. As in the previous case, the level of economic development is a variable of the capacity of a system to make investments in development technologies, food security and income stabilization. The variable selected for this component is GDP, that is has a positive correlation to adaptive capacity, while the rate of agricultural GDP shows a higher dependence on agriculture and, again, a lower adaptive capacity.

TECHNOLOGICAL ECO-EFFICIENCY. Eco-efficiency increases significantly the adaptation potential of a system. The indicators selected include GDP per unit energy use, high technology exports and CO2 emissions per capita. The development of agriculture significantly decreases the dependency of this sector on climatic variables and stabilizes production and this evolution is driven both by policies that aim for more productive crops or by private initiatives to increase the revenue from agriculture. The indicators selected for this component represent the technological advancements applied to agricultural production. Therefore these indicators have a positive correlation with the overall adaptive capacity index, as they indicate the level of independence from climatic variables.

NATURAL CAPITAL. One of the most relevant threats imposed by drought is related to the water resource system resulting in increased water scarcity. Adequate drought early warning systems depend on the reliability and vulnerability of water resource systems to confront water scarcity. Water management is related to climatic conditions, but it also depends on other factors, such as infrastructure for water storage or transport, excess of demands or their mutual incompatibility, and constraints for water management (determined by policies). Policies related to the management of natural resources are crucial to develop early warning strategies. This component needs to incorporate information related to the variability of precipitation, which decreases the general adaptation capacity of a system because of little effectiveness of developed infrastructure. In the case of agricultural systems, adaptive capacity also needs to include some variables related to the use of water in this sector, such as agricultural water use or irrigated area. These two variables show a positive correlation with the adaptive capacity because the more water is used for agriculture; the easier it is to stabilize agricultural production independently from annual precipitation or distribution.

ADULT LITERACY RATE. The proportion of the adult population aged 15 years and over which is literate (UN, 2008). Measured as a percentage. This driving force indicator responds to the need of promoting education, public awareness and training, a goal in any sustainable development program. Literacy is critical for promoting and communicating drought policy and improving the capacity of people to address drought impacts. It provides skills for effective public participation in decision making.

LIFE EXPECTANCY AT BIRTH. The average number of years that a newborn could expect to live, if he or she were to pass through life subject to the age-specific death rates of a given period (UN, 2008). It is measured in years of life expectancy at birth. This state indicator is closely connected with health conditions and determines the potential of the population for future development and growth, which in turn reflects gains in public awareness of environmental problems and public participation.

POPULATION WITHOUT ACCESS TO IMPROVED WATER. Proportion of population without access to an adequate amount of safe drinking water in a dwelling or located within a convenient distance from the user's dwelling (FAO, 2008). It is measured in percentage of total population. This state indicator is a primary element of health care of fundamental significance to the state of sanitation and the increase the risk and frequency of major diseases relevant to drought.

POPULATION BELOW THE POVERTY LINE. The proportion of population living below the poverty line, measured as total expenditure on all goods and services consumed per person and year. The poverty line adopts a different value in each country according to the development level to reflect the necessary income to attain a basic consumption and health care needs. Poverty comparisons are required for an overall assessment of human welfare and a country's progress in poverty alleviation and/or the evaluation of specific policies or projects. This state indicator reveals a number of aspects of vulnerability reduction policies in the context of drought, such as the regional or sectoral priorities for public spending to minimise impacts. The increase of poverty under drought conditions remains a major challenge for vulnerability reduction policies.

INSTITUTIONAL RELATIONS. Relations among programs, norms, and legislature related to resources management, with an emphasis on water scarcity management and drought. It is an indication of the interest of a country to incorporate drought policy into the environmental and economic concerns. Such accounts facilitate better integration among national and local governments, industry, science, interest groups, and the public in the process of developing effective approaches to reduce vulnerability to drought. This response indicator is estimated as an index from 0 to 5 evaluated by different stakeholders groups representing government, non-governmental organizations (NGOs), academia, business and media.

PUBLIC PARTICIPATION. Public participation evaluates the representation of major groups in National Councils for resources management. This response indicator is estimated as an index from 0 to 5 evaluated by different stakeholders groups representing government, non-governmental organizations (NGOs), academia, business and media. The indicator identifies the involvement of major groups in institutional mechanisms that have been created at the national level for the development and implementation of drought policies. The genuine involvement and participation of all social groups in decision making is critical to the achievement and implementation of effective early warning systems. The information provided by this indicator may be limited as it does not necessarily reflect the effectiveness of the participation of major groups in the process of policy making within national councils. There may be other channels through which major groups can participate in decision making related to drought. The results may vary considerable among countries.

TOTAL POPULATION. The total population size in a specified year. This state indicator identifies one of the crucial elements affecting vulnerability to drought and is a fundamental indicator for national decision makers with economic, social, and environmental significance.

GDP PER CAPITA. Gross domestic product (GDP) per capita is obtained by dividing annual or period GDP at current market prices by total population. It is measured in monetary units (the data of the World Bank which was used is measured GDP in US$). This driving force indicator is a basic economic growth indicator that measures the level of total economic output. It reflects changes in total production of goods and services. The indicator measures the economic capacity to respond to climate risks.

ENERGY USE. The total consumption of fossil fuel in the country, measured in kg of oil equivalent. Traditionally, energy consumption is a key aspect of economic development, but it is recognised that it has major impacts on the environment and drought.

GDP per unit energy use.GDP per unit of energy use is an indicator of the energy efficiency of a nation's economy. It is calculated as units of GDP per unit of energy used. The higher the value of the indicator, the more energy efficient the economy is.

PUBLIC EXPENDITURE. Net expenditure by a country in a given year measured in millions of €. This driving force indicator measures the public intervention in the economy and is related to the investment measures that stimulate adoption of drought policies. It is an important element of the process of vulnerability reduction, especially in areas with limited infrastructure. However, there are limitations on the use of this indicator due to differential effectiveness of public expenditures (for example arising from corruption).

FERTILISER CONSUMPTION. The extent of nitrogen fertilizer use in agriculture per unit of arable land area. It is measured in kg of N-fertilizer per hectare of arable land. This driving force indicator measures the intensity of fertilizer use, which is an indicator of agricultural technology. Very high values of this indicator may also show the potential environmental pressure from agricultural activities. Nevertheless, when comparing countries with different levels of development, N-fertiliser use is linked to agricultural technology.

TOTAL WATER USE. The total annual water use is measured in volume of water used per year. This driving force indicator shows the degree to which available water resources are being used to meet the country's water demands. It is an important measure of a country's vulnerability to water shortages, a main issue in relation to drought. The indicator can reflect the extent of water resource scarcity with increasing competition and conflict between different water uses and users.

AGRICULTURAL WATER USE. The agricultural water use measured in volume is an indicator related to the management potential of the system.

IRRIGATED AREA. Irrigated area is measured as a percentage of total cropland. This driving force indicator shows the degree of importance of irrigation within the country's agricultural sector, from the point of view of water and land resource utilization. This indicator shows to what extent arable land and water resources are already used in an intensive manner. It can indicate level of conversion of land to high input agriculture. Irrigation is linked to other intensification processes with potentially negative effects on sustainability. These negative effects are captured in the indicator "area salinised by irrigation" also used in this evaluation.

AREA SALINISED BY IRRIGATION. The area affected by salinization measured as a percentage of total agricultural area, is a state indicator that shows the degree of productive land loss, decreasing production, and associated water-born diseases that result from non-sustainable irrigation water management. This indicator is highly significant to determine degradation of land resources. It limits the possible adaptation actions to drought.

NATURAL AVAILABILITY OF WATER. Natural availability of water resources in any specific region. This availability certainly determines whether droughts are seen as a severe problem or not. In arid areas, there may even be a lack of distinction between drought and aridity (Smakhtin and Schipper 2008). Aridity is a measure of how dry/wet a region is on average over the long term; it is a permanent climatic characteristic of an area. In arid areas, however, the intraannual variability of precipitation is generally higher than in humid areas. Figure 1 illustrates this point. Figures 1(a) and 1(b) show the distribution of mean annual precipitation on a global scale and the distribution of the coefficient of variation (CV) of mean annual precipitation, respectively.

6. VULNERABILITY IN THE CASE STUDIES

When moving from large scales to national and local scales, the local conditions will strongly influence whether a dry period is experienced as a drought, i.e. to what degree a specific local activity or group of water users is vulnerable to droughts (Wilhite and Glantz, 1985).

The objective is to ensure that the research not only brings the state-of-the-art in drought related research to the operational domain, but also provide viable and effective solutions with direct applicability in Africa.

Vulnerability indices based on damage incurred and population affected in the case studies (Figure 22) need to include other indicators different than the analysis at the continental level, since it is important to assess the damage to social groups, households, and concrete environmental areas.

Figure 22 Map of Africa showing the basins considered in the comparative case studies (note that a case study focusing on comparison of European and African approaches is not depicted).

The Case Studies may need to use different vulnerability indicators based on the focus and drought management goals (

Table 3). Some of the indicators discussed with the case studies are presented in Table 4.

The Oum er Rbia River Basin (Morocco, Northern Africa) focuses on improving capabilities in the forecasting of agricultural drought and establishing guidelines on adaptation in agricultural practices to reduce vulnerability. The Eastern Nile Basin (North & Eastern Africa) focuses on improved tools for the forecasting of water availability, the impact of climate change and community scale adaptation. The Limpopo Basin (Southern Africa) focuses on improving existing drought monitoring and forecasting capabilities, as well as institutions, policies, guidelines and procedures for management of the scarce water resources in the basin. The Niger Basin (Western Africa) focuses on mid-term climate forecasting and strengthening preparedness to droughts to improve food security and human welfare.

Table 3 Summary of the suggested indicators in the case studies based on the objectives and the tools and models available in Dewfora

Case study	Focus of the early warning	Suggested indicators
Oum-er-Rbia Basin	Agriculture Water release to irrigation Agric. Practices Water allocation among users Strategic importance providing water to irrigated and rain-fed agriculture, mining, large manufacturing industries, and water transfers to large cities, including Casablanca and Marrakech. Optimisation of water release to irrigators and analyze the effectiveness of adapted agricultural practices on vulnerability. Optimisation of crop management to dryland, early warning doe insurance Committee that takes decisions on drought	Streamflow, crop yield, rainfall, adaptive capacity, exposure SPI, NAO? Vulnerability
Niger River basin	Rainfall forecasting Wetlands Rainfed agriculture Food security, poverty Encompasses nine countries, about 30% of the basin is located in Mali, one of the poorest countries in the world where agriculture is a main economic activity that depends on the onset and intensity of the annual monsoon Application of a mesoscale distributed eco-hydrological model combining hydrology, vegetation and agriculture. Pilot the drought preparedness by predicting future hydrological and agricultural drought risk through climate projections. Wetlands in the inner Niger delta.	Precipitation, streamflow, reservoir operation, state of ecosystems, adaptive capacity, esposure Predictive indicator? Coping capacity
Limpopo Basin	Institutional structure Water management Only source of water for millions of people, shared basin Improve the flow of information Mental model Regional analysis because the shared basin has sto have a good coordination strucuture To give the gap analysis, to look into the institutional set-up Provide recommendations for improving institutional structure Include several types of end-users and analyze how the issued warnings flow through the institutional structure	Precipitation, streamflow, crop yields, management rules, institutional response, adaptive capacity, exposure Social response
Eastern Nile Basin	Development Water allocation and management Only source of water for millions Transboundary Only source of water for millions of people Water allocation is a controversial issue and cause of tensions between the countries, analyse Blue Nile and Atbara Basins	Hydrological indicators, adaptive capacity, exposure SWSI and ENSO Social response

Table 4 Indicators for early warning in water resources systems

Type of information	Indicators required	Early warning application
Permanent monitoring	Precipitation, temperature, river flows, reservoir levels and planned releases, NDWI, soil moisture, groundwater	Onset of the rainy season Reservoir inflows to support decisions on water management
Seasonal forecast and medium range forecast	Precipitation, temperature, evaporation	Onset of the rainy season Reservoir inflows to support decisions on water management Development of local water resources such as ponds or rain harvesting Decisions on the extraction of groundwater Expected rainfall over irrigated areas as well as for inflows to reservoirs to allow an optimal release strategy to be established Released to irrigators could be reduced if rainfall is predicted, whilst releases could be augmented to bridge an unexpected dry spell and reduce plant stress.

Recognizing the importance that representative stakeholders need to evaluate vulnerability within the DEWFORA case studies, the stakeholders in each case study may be engaged directly in the evaluation of vulnerability. The process will contribute to the acceptance and trust of the science that feeds into the Drought Early Warning System proposal that will result from DEWFORA. In relation to drought management, stakeholders can be individuals, organisations, institutions, decision-makers, or policy-makers, who determine or are affected by water use and exposure drought and water scarcity. Table 5 provides a number of potential drought impacts that may be useful to characterise drought vulnerability in the case studies.

Table 5 Guideline for ranking vulnerability in the case studies. Rank from 0 (not important) to 5 (extremely important). Check if data for quantitative evaluation is available.

Possible drought vulnerability in the Case study	Rank 0 to 5	Data y or n
I. Social		
Appearance of human health related problems		
Conflict appearance in political decisions		
Conflict appearance in water use		
Decreased nutrition quality in subsistence farm areas		

Increase in the poverty level in rural areas		
Increased migration to urban areas form agricultural areas		
II. Environmental		
Biodiversity loss in ecosystems associated with water		
Biodiversity loss in land based ecosystems		
Changes in estuarine areas (e.g., salinity levels)		
Changes in the migration and concentration of animal species (loss of wildlife in some areas and too many species in others)		
Decrease in reservoir and lake levels		
Ground water depletion and land subsidence		
Increase erosion of soils by wind and water		
Increase in diseases in wild animals (e.g., due to low quality of water or poor feed)		
Increase in diseases in plants (e.g., due to low quality of water)		
Increase in invasive weeds and algae		
Increase in number and severity of fires		
Increased stress to endangered species		
Reduction of the wetland areas		
Water quality effects (e.g., salt concentration, increased water temperature, pH, dissolved oxygen, turbidity)		
III. Water supply systems		
Reduced service quality		
Decrease in hydroelectric power generation		
Increase in water tariffs		
Increase in water treatment costs		
Additional cost of supplemental water infrastructures		
Increased cost of ground water extraction		
IV. Agriculture, fisheries and forestry		
Decrease in farm income		
Decrease in land prices		
Decrease in livestock feed quantity and quality		
Decrease in rangeland and pasture production		
Decreased crop production		
Decreased crop quality		
Decreased water in farm ponds for irrigation		
Increase in crop imports		
Increase in food prices		
Increase in insects, pests, and crop diseases		
Increase in livestock diseases		
Increased unemployment of the agricultural sector		
Livestock production: water quality and quantity		
Loss of income of industries dependent on agriculture		
Losses in financial institutions related to agricultural activities (e.g., credit risks)		
Revenue losses to state and local governments (from reduced tax base to farmers)		
Decrease production of fishery		
Decreased production of forests		
V. Industry		
Changes in the energy cost (e.g., due to changes in hydroelectric by oil)		
Electric power unbalance (Increased energy demand and reduced supply)		
VI. Other		
Please specify		

To characterise the underlying causes of vulnerability we propose a method for analysis is to develop a matrix that lists the impact as well as the described basal causes of the impact.

The following sequence of questions may be helpful in identifying potential causes:

– Is there some basal cause, or aspect of the basal cause, that cannot be modified and must be accepted as a drought-related risk for this activity or area?

– Can the basal cause be mitigated (can it be modified before a drought)? If yes, then how?

– Can the basal cause be responded to (can it be modified during or after a drought)? If so, then how?

The information provided in Table 6 may assist stakeholders to evaluate the causes of vulnerability and take actions to develop mitigation and early warning systems.

Table 6 Guidelines for the evaluation of the potential impact and causes of drought

Impact of Drought	Possible underlying causes of vulnerability (Why is the system vulnerable?)	Comments: (What actions may reduce vulnerability?)
Income loss from crop failure	Variable climate	Improve weather monitoring
	Lack of water for irrigation	Develop a plan to solve conflict with urban users
	Expensive drought tolerant seeds	Subsidize seed sales
	Farmer preferences to plant specific seeds	Conduct workshops, enhance communication to conduct research
	Lack of Government incentives to plant drought tolerant crops	Lobby for new incentives
	No drought warning	Provide weather monitoring
		Identify “triggers”
	High cost of crop insurance	Government subsidies
	Lack of research as to the efficiency of drought relief efforts	Identify target groups and conflicting relief program criteria and goals
	Lack of drought relief program coordination	Streamline relief application and funding

6.1 CHECKLIST AND RANKING OF POTENTIAL IMPACTS

Some of the more common types of drought impacts are in the economic, environmental, and social sectors. Table 2 summarizes the main impacts to be considered in each sector (details are given in Table 3). Similar approaches are proven to be very effective in evaluating the impacts of drought in a range of case studies (Willhite and Buchanan-Smith, 2005). Recent drought impacts, especially if they are associated with severe to extreme drought, are ranked more heavily than the impacts of historical drought, since recent events more accurately reflect current vulnerabilities. The analyses produces a range of impacts related to the severity of drought and highlights sectors, populations, or activities that are vulnerable to drought.

The aim is to identify the direct consequences of drought, such as reduction in crop yield, reservoir depletion, and also the secondary consequences of drought such as land abandonment due to reduced crop yields and subsequent loss of farm income. This includes the application of the drought indices to establish correlations with the variables that represent the affected sectors, for example, the correlation of the SPI with the crop yields or with water availability.

Drought management depends on indices to detect drought conditions, and thresholds to activate drought responses. Indices and thresholds are important to detect the onset of drought conditions, to monitor and measure drought events, and to reduce drought impacts.

Risk in hydrological systems is directly related to water scarcity, which differs from drought because it is related to a shortage of water availability to satisfy demands. The shortage results from an unbalance between water supply and demand, which is originated by a meteorological phenomenon, but is also conditioned by other time-varying factors, such as demand development, supply infrastructure and management strategies. The result of the unbalance is demand deficit, which is of concern for water managers.

Risk analysis in hydrological systems consists on identifying demands that may not be fully satisfied with available water resources, and quantifying the estimated impacts of water shortage. The acceptable risk level is conditioned by available water resources and infrastructure and depends on demand characteristics and their elasticity. In this context, the risk analysis should consider the following aspects: (a) Probability of failure occurrence (probability of not satisfying the demand), (b) Severity of failures (magnitude of the deficit), (c) Failure duration (time span when deficits occur), (d) Economic impact of failures, and (e) Unexpected climatic events which magnitude or duration is not included in the available time series which has to be considered when setting up the guarantees.

7. LINKAGES TO POLICY

7.1 SOME POLICY MESSAGES

(to be completed)

Risk vs vulnerability reduction approaches, the following assertions can be made:

The impacts of drought are created by context

Understanding and reducing vulnerability does not demand accurate predictions of the incidence of extreme drought

It is politically difficult to justify vulnerability reduction on economic grounds

Risk-based approaches to preparing for drought are focused on acquiring accurate probabilistic information about the events themselves. When this is not possible, the strategy fails

Risk-based approaches to covering the costs of drought and water scarcity not depend for their success on reduction of vulnerability

Some considerations:

Drought impacts vary according to location and enterprise type and the effectiveness of risk management practices adopted.

Drought create winners and losers. Drought induces output prices increases benefiting unaffected farmers by drought whereas increases input prices may hurt them.

Economic impacts are a global process: Involves enterprise, imply intra- and inter-sectoral adjustment, global implications through internationally traded volumes and prices.

In the global context: the scale of drought impacts is likely different in developed countries (well developed market and welfare system) compared with impacts in lesser developed (sometimes heavily dependent on agriculture).

7.2 LINKAGES TO EU POLICY

In 2007 the European Commission addressed these challenges in a Communication on water scarcity and droughts in the European Union. The Communication identified 7 main policy options to address water scarcity and drought issues:

(1) Putting the right price tag on water

(2) Allocating water and water-related funding more efficiently

(3) Improving drought risk management

(4) Considering additional water supply infrastructures

(5) Fostering water efficient technologies and practices

(6) Fostering the emergence of a water-saving culture in Europe

(7) Improve knowledge and data collection

Given the huge potential for water savings in the EU, the Communication laid down a water hierarchy under which water demand management should come first, and alternative supply options should only be considered once the potential for water savings and efficiency has been exhausted.

For further information see: http://ec.europa.eu/environment/water/quantity/scarcity_en.htm

http://www.watercore.eu/

8. FURTHER INFROMATION

Adejuwon, J. 2006. Food Security, Climate Variability and Climate Change in Sub Saharan West Africa. AIACC Final Reports: Project No. AF 23. Washington, DC, USA: The International START Secretariat.

Alley, W.M. 1984. The Palmer Drought Severity Index: limitations and assumptions. Journal of Climate and Applied Meteorology 23:1100-1109.

Arnell NW (1999) Climate change and global water resources, Global Environmental Change, Vol 9, Suppl 1, October, pp S31-S49

Bates, B.C.; Kundzewicz, Z. W.; Wu, S.; Palutikof, J. P. (eds.) 2008. Climate Change and Water: Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat. 210 pp.

Bazza, M. 2002. Water resources planning and management for drought mitigation. FAO regional Workshop on Capacity Building on Drought Mitigation in the Near East, Rabat, Morocco 1- 5 November 2002.

BCPR (UNDP Bureau for Crisis Prevention and Recovery). 2004. Reducing Disaster Risk: A Challenge for Development.

Below, R.; Grover-Kopec, E.; Dilley, M. 2007. Documenting Drought-Related Disasters. The Journal of Environment & Development 16(3): 328-344.

Bernardino, M. C.; Corte Real, J. 2004. A Drought Risk Assessment for Europe. Geophysical Research Abstracts 6: 03742.

Birkmann, J. 2007. Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. Environmental Hazards. 7:20-31.

Blaikie, P., T. Cannon, I. Davis, and B. Wisner. 1994. At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge Publishers, London, UK.

Botterill, L.C. and D.A. Wilhite (eds). 2005. From disaster response to risk management. Springer, The Netherlands

Brenkert A, Malone E (2005), 'Modeling vulnerability and resilience to

Burke, E. J.; Brown, S. J.; Christidis, N. 2006. Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model. Journal of Hydrometeorology 7: 1113– 1125. Cardona, O. D. 2007. A System of Indicators for Disaster Risk Management in the Americas. Proceedings of Conference on Globalization, Diversity, and Inequality in Latin America: The Challenges, Opportunities, and Dangers. Pittsburgh: University of Pittsburgh.

Burke, E. J.; Brown, S. J.; Christidis, N. 2006. Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model. Journal of Hydrometeorology 7: 1113– 1125.

Burton I (1997) Vulnerability and adaptive response in the context of climate and climate change Climatic Change, 36, 185-196

Cancelliere, A., B. Bonaccorso, and G. Rossi. 2004. Drought identification and characterization by RUN method.

Cardona, O. D. 2007. A System of Indicators for Disaster Risk Management in the Americas. Proceedings of Conference on Globalization, Diversity, and Inequality in Latin America: The Challenges, Opportunities, and Dangers. Pittsburgh: University of Pittsburgh.

Comprehensive Assessment of Water Management in Agriculture. 2007. Water for food, water for life: A comprehensive assessment of water management in agriculture. London: Earthscan, and Colombo: International Water Management Institute.

Cramer, W.; Bondeau, A.; Woodward, F. I.; Prentice, I. C.; Betts, R. A.; Brovkin, V.; Cox, P. M.; Fisher, V.; Foley, J. A.; Friend, A. D.; Kucharik, C.; Lomas, M. R.; Ramankutty, N.; Sitch, S.; Smith, B.; White, A.; Young–Molling, C. 2001. Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models. Global Change Biology 7: 357–373.

CRED. 2004. http://www.cred.be/emdat/profiles/disaster/drought.htm

Dai, A.; Trenberth, K. E.; Qian, T. 2004. A Global Dataset of Palmer Drought Severity Index for 1870–2002: Relationship with Soil Moisture and Effects of Surface Warming. Journal of Hydrometeorology 5: 1117-1130.

Dettinger, M. D.; Diaz, H. F. 2000. Global Characteristics of Stream Flow Seasonality and Variability. Journal of Hydrometeorology 1(3): 289-310.

Dilley, M.; Chen, R. S.; Deichmann, U.; Lerner-Lam, A.; Arnold, M. 2005. Natural disaster hotspots: A global risk analysis. Washington, DC: World Bank, Hazard Management Unit.

Doesken, N.J.; T.B. McKee; and J. Kleist. 1991. Development of a surface water supply index for the western United States. Climatology Report Number 91–3, Colorado State University, Fort Collins, Colorado.

Dow, K.; Downing, T. E. 2006. The Atlas of Climate Change. Mapping the World's Greatest Challenge. London: Earthscan and Stockholm: Stockholm Environment Institute.

Downing, T. E.; Butterfield, R.; Cohen, S.; Huq, S.; Moss, R.; Rahman, A.; Sokona, Y.; Stephen, L. 2001. Vulnerability Indices: Climate Change Impacts and Adaptation. Policy Series 3: United Nations Environment Programme. European Environment Agency. 2003. Mapping the impacts of recent natural disasters and technological accidents in Europe. Copenhagen, Denmark: European Environment Agency. European Environment Agency. 2004. Impacts of Europe's Changing Climate: An indicator-based assessment. Luxembourg: Office for Official Publications of the European Communities.

Downing, T. E.; Butterfield, R.; Cohen, S.; Huq, S.; Moss, R.; Rahman, A.; Sokona, Y.; Stephen, L. 2001. Vulnerability Indices: Climate Change Impacts and Adaptation. Policy Series 3: United Nations Environment Programme.

Edwards, D.C.; and T. B. McKee. 1997. Characteristics of 20th century drought in the United States at multiple time scales. Climatology Report Number 97–2, Colorado State University, Fort Collins, Colorado.

EEA, 2009. Water resources across Europe — confronting water scarcity and drought. EEA Report No 2/2009. European Environment Agency, Copenhagen. EEA Report No 2/2009, available at http://www.eea.europa.eu/publications/water-resources-across-europe

Eriyagama N, Smakhtin V, Gamage N (2009) Mapping Drought Patterns and Impacts: A Global Perspective. International Water Management Institute. IWMI Research 133, Sri Lanka *****

European Environment Agency. 2003. Mapping the impacts of recent natural disasters and technological accidents in Europe. Copenhagen, Denmark: European Environment Agency.

Falkenmark, M. 1989. The Massive Water Scarcity Now Threatening Africa – Why isn't It Being Addressed? Ambio 18: 112-118.

Falkenmark, M.; Berntell, A.; Jägerskog, A.; Lundqvist, J.; Matz, M.; Tropp, H. 2007. On the Verge of a New Water Scarcity: A Call for Good Governance and Human Ingenuity. SIWI Policy Brief. Sweden: Stockhom International Water Institute.

FAO (2006) FAOSTAT and AQUASTAT Database Collections. In Internet: http://www.fao.org, Food and Agriculture Organization of the United Nations, Rome. Last visited December 2006.

FAO (Food and Agriculture Organization of the United Nations). 2000. New Dimensions in Water Security; Water, Society and Ecosystem Services in the 21 st Century. Rome: Food and Agriculture Organization of the United Nations.

Fischer, G., van Velthuizen, H.; Shah, M.; Nachtergaele, F. 2002b. Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results. RR-02-02. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA) and Rome, Italy: Food and Agriculture Organization of the United Nations.

Fischer, G.; Shah, M.; van Velthuizen, H. 2002a. Climate Change and Agricultural Vulnerability. Special report to the World Summit on Sustainable Development, Johannesburg 2002. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA).

Fleig, A. K.; Tallaksen, L. M.; Hisdal, H.; Demuth, S. 2006. A global evaluation of streamflow drought characteristics. Hydrology and Earth System Sciences 10: 535-552. Hashimoto, T.; Stedinger, J. R.; Loucks, D. P. 1982. Reliability, Resiliency, and Vulnerability Criteria for

Water Resource System Performance Evaluation. Water Resources Research 18(1): 14-20. 22

Fleig, A. K.; Tallaksen, L. M.; Hisdal, H.; Demuth, S. 2006. A global evaluation of streamflow drought characteristics. Hydrology and Earth System Sciences 10: 535-552.

Flores, F., L.M. Garrote, F.J. Martín Carrasco. 2003. The hydrologic regime of the Tagus basin in the last 60 years. World Water Congress, Madrid, Spain

Freshwater Systems. Washington, DC: World Resources Institute. Schröter, D.; Acosta-Michlik, L.; Arnell, A. W.; Araújo, M. B.; Badeck, F.; Bakker, M.; Bondeau, A.; Bugmann, H.; Carter, T.; de la Vega-Leinert, A. C.; Erhard, M.; Espiñeira, G. Z.; Ewert, F.; Fritsch, U.; Friedlingstein, P.; Glendining, M.; Gracia, C. A.; Hickler, T.; House, J.; Hulme, M.; Kankaanpää, S.; Klein, R. J. T.; Krukenberg, B.; Lavorel, S.; Leemans, R.; Lindner, M.; Liski, J.; Metzger, M. J.; Meyer, J.; Mitchell, T.; Mohren, F.; Morales, P.; Moreno, J. M.; Reginster, I.; Reidsma, P.; Rounsevell, M.; Pla, E.; Pluimers, J.; Prentice, I. C.; Pussinen, A.; Sánchez, A.; Sabaté, S.; Sitch, S.; Smith, B.; Smith, J.; Smith, P.; Sykes, M. T.; Thonicke, K.; Thuiller, W.; 23 Tuck, G.; van der Werf, G.; Vayreda, J.; Wattenbach, M.; Wilson, D. W.; Woodward, F. I.; Zaehle, S.; Zierl, B.; Zudin, S.; Cramer, W. 2004. ATEAM Final Report. Potsdam, Germany: Potsdam Institute for Climate Impact Research (PIK).

Garrote L, Iglesias A, Flores F. 2008. Development of drought management plans in Spain. In: Iglesias A, Cancelliere A, Cubillo F, Garrote L, Wilhite DA (eds), Coping with drought risk in agriculture and water supply systems: Drought management and policy development in the Mediterranean. Springer, The Netherlands.

Garrote L., Martín-Carrasco, F., Flores-Montoya, F. and Iglesias, A. (2007) Linking Drought Indicators to Policy Actions in the Tagus Basin Drought Management Plan. Water Resources Management 21(5), pp. 873-882

Garrote L., Martín-Carrasco, F., Flores-Montoya, F. and Iglesias, A. (2007) Linking Drought Indicators to Policy Actions in the Tagus Basin Drought Management Plan. Water Resources Management 21(5), pp. 873-882

Garrote, L., and Flores, F. and F.J. Carrasco. 2003. The hydrologic regime of the Tagus basin in the last 60 years. IWRA Congress. October 2003.

Gibbons J and Ramsden SJ (2005) Robustness of recommended farm plans in England under climate change: A monte carlo simulation. Climatic change. 68(1-2), 113-133.

Gibbs, W.J.; and J.V. Maher. 1967. Rainfall deciles as drought indicators. Bureau of Meteorology Bulletin No. 48, Commonwealth of Australia, Melbourne.

GLASOD.htm (accessed in December 2008). Jülich, S. 2006. Drought risk indicators for assessing rural households. Presentation made at Global Water Hotspots: Water-related social vulnerabilities and resilience-building, Summer Academy for Social Vulnerability. Hohenkammer, Germany: United Nations University and Munich Re Foundation. Available at www.ehs.unu.edu/file.php?id=165 (accessed in December 2008).

Goeree, Jacob K. & Holt, Charles A. & Palfrey, Thomas R., (2002). Quantal Response Equilibrium and Overbidding in Private-Value Auctions. Journal of Economic Theory, Elsevier, 104(1), 247-272.

Gommes, R.; and F. Petrassi. 1994. Rainfall variability and drought in Sub-Saharan Africa since 1960. Agrometeorology Series Working Paper No. 9, Food and Agriculture Organization, Rome, Italy.

Guttman, N.B. 1998. Comparing the Palmer Drought Index and the Standardized Precipitation Index. Journal of the American Water Resources Association 34(1):113-121.

Hashimoto, T.; Stedinger, J. R.; Loucks, D. P. 1982. Reliability, Resiliency, and Vulnerability Criteria for Water Resource System Performance Evaluation. Water Resources Research 18(1): 14-20. 22

Hayes, M., M. Svoboda, D. Wilhite, and O. Vanyarkho. 1999. Monitoring the 1996 drought using the SPI. Bulletin of the American Meteorological Society 80:429-438.

Horion S, Kurnik B, Barbosa P, Vogt J (2010) Improved drought monitoring in the Greater Horn of Africa by combining meteorological and remote sensing based indicators. Geophysical Research Abstracts, Vol. 12, EGU2010-11567, 2010, EGU General Assembly 2010

IAHS (Ad Hoc Group on Global Water Data Sets.) 2001. Global water data: A Newly Endangered Species. Co-authored by C.J. Vörösmarty (lead), A. Askew, R. Barry, C. Birkett, P. Döll, W. Grabs, A. Hall, R. Jenne, L. Kitaev, J. Landwehr, M. Keeler, G. Leavesley, J. Schaake, K. Strzepek, S.S. Sundarvel, K. Takeuchi, and F. Webster. AGU Eos Transactions 82:5 54, 56, 58.

ICSU/WFEO. 2004. Harnessing Science and Technology for Sustainable Development: Water, Sanitation and Human Settlements. Dialogue Paper by the Scientific and Technological Community to the Twelfth Session of the Commission on Sustainable Development (CSD12), 19 - 30 April 2004. The International Council for Science (ICSU) and the World Federation of Engineering Organisations (WFEO) as organizing partners of the Scientific and Technological Community.

Iglesias A, Cancelliere A, Cubillo F, Garrote L, Wilhite DA (2009) Coping with drought risk in agriculture and water supply systems: Drought management and policy development in the Mediterranean. Springer, The Netherlands.

Iglesias A, Garote L, F Flores, and M Moneo (2007b) Challenges to manage the risk of water scarcity and climate change in the Mediterranean Water Resources Management, Accepted, 2006 forthcoming (A Iglesias and L Garrote, guest editors)

Iglesias A, Garrote L, Diz A, Schlickenrieder J, Martin-Carrasco F (2011) Re-thinking water policy priorities in the Mediterranean region in view of climate change. Environmental Science & Policy, Volume 14, Issue 7, November 2011, Pages 744-757

Iglesias A, Moneo M (eds) (2005) Drought preparedness and mitigation in the Mediterranean: Analysis of the Organizations and Institutions. Options Méditerranéenness. Paris.

Iglesias A, Mougou R, Moneo M (2007) Adaptation of Mediterranean agriculture to climate change. In: Key vulnerable regions and climate change, Battaglini A (ed), European Climate Forum, Germany

Iglesias A., M. Moneo, L. Garrote and F. Flores. 2005. Drought risk and climate change. In Water Resources in Spain. Llamas, M. R. And A. Garrido (eds). Resources for the Future, Washington D. C:

Iglesias, A. and M. Moneo (eds). 2005. Drought Preparedness and Mitigation in the Mediterranean: Analysis of the Organizations and Institutions. Options Méditerranénnnes, Série B, No. 51. Zaragoza: CIHEAM. ISBN: 2-85352-320-9.

Ionescu C, Klein RJT, Hinkel J, Kumar KSK, Klein R (2007) Towards a formal framework of vulnerability to climate change. Environmental Modeling and Assessment (Submitted)

IPCC (2007) Climate Change (2007): Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge

ISRIC (International Soil Reference and Information Centre). 1990. Global Assessment of Human-induced Soil Degradation (GLASOD) Data Set. Available at www.isric.org/UK/About+ISRIC/Projects/Track+Record/ GLASOD.htm (accessed in December 2008).

Jülich, S. 2006. Drought risk indicators for assessing rural households. Presentation made at Global Water Hotspots: Water-related social vulnerabilities and resilience-building, Summer Academy for Social Vulnerability. Hohenkammer, Germany: United Nations University and Munich Re Foundation. Available at www.ehs.unu.edu/file.php?id=165 (accessed in December 2008).

Karl, T.R.; and R.W. Knight. 1985. Atlas of Monthly Palmer Hydrological Drought Indices (1931–1983) for the Contiguous United States. Historical Climatology Series 3–7, National Climatic Data Center, Asheville, North Carolina.

Kassel, Germany: Center for Environmental Systems Research, University of Kassel. Lloyd-Hughes, B.; Saunders, M. A. 2002. A Drought Climatology for Europe. International Journal of Climatology 22: 1571–1592.

Kerr, Richard A. 2005. Millennium's Hottest Decade Retains its Title, for Now, Science 307, 11 February.

Kilsby, C. G. (ed.). 2001. Final Report of the WRINCLE Project, Project Number ENV4-CT97-0452 of the European Union Environment and Climate Research Programme, pp. 47–53. Available at www.ncl.ac.uk/ wrincle/ (accessed in December 2008).

Lanen, H.A.J., and E. Peters. 2000. Definition, Effects and Assesment of groundwater droughts. In J.V. Vogt and F. Somma (eds.), Drought and drought mitigation in Europe, pp 49-61. Kluwer Academic Publishers. Netherlands.

Le Houérou, H.N.; G.F. Popov; and L. See. 1993. Agrobioclimatic classification of Africa. Agrometeorology Series Working Paper No. 6, Food and Agriculture Organization, Rome, Italy.

Lehner, B.; Döll, P.; Alcamo, J; Henrichs, T.; Kaspar, F. 2006. Estimating the impact of global change on flood and drought risks in Europe: A continental integrated analysis. Climatic Change 75: 273–299.

Lehner, B.; Henrichs, T.; Döll, P.; Alcamo, J. 2001. EuroWasser – Model-based assessment of European water resources and hydrology in the face of global change. Kassel World Water Series 5. Chapters 5 and 7. Kassel, Germany: Center for Environmental Systems Research, University of Kassel.

Limaye AS, Paudel KP, Musleh F, Cruise JF, Hatch LU., (2004). Economic impacts of water allocation on agriculture in the lower Chattahoochee river basin. Hydrological Science and Technology Journal. 20(1-4), 75-92.

Llamas, M. R. 2000. Some lessons learnt during the drought in 1991-1995. Pages 253-264 in Drought and drought mitigation in Europe, Vogt J., V. and F. Somma (editors). Kluwer Academic Publishers, The Netherlands. 325 pages

Lloyd-Hughes, B.; Saunders, M. A. 2002. A Drought Climatology for Europe. International Journal of Climatology 22: 1571–1592.

Lobell DB and Ortiz-Monasterio JI., (2006). Regional importance of crop yield constraints: Linking simulation models and geostatistics to interpret spatial patterns. Ecological Modelling 196, 173–182.

Loucks, D. P. 1997. Quantifying trends in system sustainability. Hydrological Sciences Journal 42(4): 513-530.

Malik, L. K.; Koronkevich, N. I.; Zaitseva, I. S.; Barabanova, E. A. 2000. Development of Dams in the Russian Federation and NIS Countries, A WCD briefing paper prepared as an input to the World Commission on Dams. Available at www.dams.org (accessed in September 2008). McMahon, T. A.; Adeloye, A. J.; Zhou, S. L. 2006. Understanding performance measures of reservoirs. Journal of Hydrology 324(1-4): 359-382.

Malik, L. K.; Koronkevich, N. I.; Zaitseva, I. S.; Barabanova, E. A. 2000. Development of Dams in the Russian Federation and NIS Countries, A WCD briefing paper prepared as an input to the World Commission on Dams. Available at www.dams.org (accessed in September 2008).

Mas-Collel, A., Whinston, M.D., Green, J.R., (1995). Microeconomic Theory. Oxford University Press. New York.

McKee, T.B., N.J. Doeskin, and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. pp. 179-184. Proceedings of the Eighth Conference on Applied Climatology, Anaheim, CA, January 17-23, 1993. American Meteorological Society. Boston, MA.

McMahon, T. A.; Adeloye, A. J.; Zhou, S. L. 2006. Understanding performance measures of reservoirs. Journal of Hydrology 324(1-4): 359-382. Middleton, N.; Thomas, D. (eds.). 1997. World Atlas of Desertification, 2nd edition. 182 pp. London: Edward Arnold.

Middleton, N.; Thomas, D. (eds.). 1997. World Atlas of Desertification, 2nd edition. 182 pp. London: Edward Arnold.

Mitchell, T. D.; Carter, T. R.; Jones, P. D.; Hulme, M.; New, M. 2004. A comprehensive set of high resolution grids of monthly climate for Europe and the globe: The observed record (1901-2000) and 16 scenarios (2001- 2100). Tyndall Centre Working Paper 55.

Moneo M (2007) Agricultural vulnerability of drought: A comparative study in Morocco and Spain. IAMZ-CIHEAM, Zaragoza.

Moss, R. et al. (2000), Measuring Vulnerability: A Trial Indicator Set. Pacific Northwest National Laboratory, Richland, WA, USA.

NDMC and ISDR. 2004. National Drought Mitigation Center and International strategy for disaster reduction. Report: Living with risk. http://www.unisdr.org/unisdr/Globalreport.htm

NDMC. 2004. National Dorught Mitigation Center. http://www.drought.unl.edu

O'Brien, K.; Leichenko, R.; Kelkar, U.; Venema, H.; Aandahl, G.; Tompkins, H.; Javed, A.; Bhadwal, S. 2004. Mapping Vulnerability to Multiple Stressors: Climate Change and Globalization in India. Global Environmental Change 14: 303-313.

Palacios-Huerta, I., (2003). An Empirical Analysis of the Risk Properties of Human Capital Returns. American Economic Review, American Economic Association, 93(3), 948-964.

Palmer, W.C. 1965. Meteorological drought. Research Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington, D.C.

Palmer, W.C. 1968. Keeping track of crop moisture conditions, nationwide: The new Crop Moisture Index. Weatherwise 21:156–161.

Peel, M. C.; McMahon, T. A.; Pegram, G. G. S. 2005. Global analysis of runs of annual precipitation and runoff equal to or below the median: run magnitude and severity. International Journal of Climatology 25: 549-568.

Peel, M. C.; Pegram, G. G. S.; McMahon, T. A. 2004. Global Analysis of Runs of Annual Precipitation and Runoff Equal to or below the Median: run length. International Journal of Climatology 24: 807-822.

Ramankutty, N.; Foley, J. A. 1998. Characterizing patterns of global land use: An analysis of global croplands data. Global Biogeochemical Cycles 12(4): 667-685.

Reilly J and D Schimmelpfennig (1999) Agricultural impact assessment, vulnerability, and the scope for adaptation Climatic Change, 43, 745-788

Revenga, C.; Brunner, J.; Henninger, N.; Kassem, K.; Payne, R. 2000. Pilot Analysis of Global Ecosystems: Freshwater Systems. Washington, DC: World Resources Institute.

Ribot, J.C., A. Najam, and G. Watson. 1996. Climate Variation, Vulnerability and Sustainable Development in the Semi-arid Tropics. In J.C. Ribot, A.R. Magalhães, and S.S. Panagides (eds.) Climate Variability, Climate Change and Social Vulnerability in the Semi-arid Tropics. Cambridge University Press, New York, NY.

Rojas O, Vrieling A, Rembold F, (2011) Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery. Remote Sensing of Environment 115 (2011) 343–352

Rossi G, Cancelliere A, Pereira LS, Oweis T, Shataniawi M and Zairi A (eds), (2003). Tools for drought mitigation in Mediterranean Regions. Kluver Academic Publishers, The Netherlands. 357 p.

Rossi, G. and Cancelliere, A. 2003. At site and regional drought identification by REDIM model. In: Tools for Drought mitigation in Mediterranean Regions. Rossi et al., eds. Pp 37-54

Rossi, G., A. Cancelliere, L.S. Pereira, T. Oweiss, M. Shatanawi, and A. Zairi (eds). 2003. At Tools for Drought mitigation in Mediterranean Regions. 339 pp. Kluver Accademic Publishers, London.

Scholes, R. and R. Hassan (Working Group Leaders). 2005. The Millennium Ecosystem Assessment, Volume 1: Conditions and Trends Working Group Report. Island Press. In press.

Schröter, D.; Acosta-Michlik, L.; Arnell, A. W.; Araújo, M. B.; Badeck, F.; Bakker, M.; Bondeau, A.; Bugmann, H.; Carter, T.; de la Vega-Leinert, A. C.; Erhard, M.; Espiñeira, G. Z.; Ewert, F.; Fritsch, U.; Friedlingstein, P.; Glendining, M.; Gracia, C. A.; Hickler, T.; House, J.; Hulme, M.; Kankaanpää, S.; Klein, R. J. T.; Krukenberg, B.; Lavorel, S.; Leemans, R.; Lindner, M.; Liski, J.; Metzger, M. J.; Meyer, J.; Mitchell, T.; Mohren, F.; Morales, P.; Moreno, J. M.; Reginster, I.; Reidsma, P.; Rounsevell, M.; Pla, E.; Pluimers, J.; Prentice, I. C.; Pussinen, A.; Sánchez, A.; Sabaté, S.; Sitch, S.; Smith, B.; Smith, J.; Smith, P.; Sykes, M. T.; Thonicke, K.; Thuiller, W.; 23

Shafer, B.A.; and L.E. Dezman. 1982. Development of a Surface Water Supply Index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. In Proceedings of the Western Snow Conference, pp. 164–175. Colorado State University, Fort Collins, Colorado.

Sheffield, J. 2008. Global drought in the 20th and 21st centuries: Analysis of retrospective simulations and future projections of soil moisture. PhD thesis. Princeton, USA: Princeton University. Sheffield, J.; Wood, E. F. 2007a. Characteristics of global and regional drought, 1950–2000: Analysis of soil moisture data from off-line simulation of the terrestrial hydrologic cycle. Journal of Geophysical Research 112: D17115. doi:10.1029/2006JD008288.

Sheffield, J.; Wood, E. F. 2007b. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics 31(1): 79-105.

Sheffield, J.; Wood, E. F. 2007b. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics 31(1): 79-105. Smakhtin, V. U.; Schipper, E. L. 2008. Droughts: the impact of semantics and perceptions. Water Policy 10(2): 131-143.

Smakhtin, V. U.; Schipper, E. L. 2008. Droughts: the impact of semantics and perceptions. Water Policy 10(2): 131-143.

Smith, D.I.; M.F. Hutchinson; and R.J. McArthur. 1993. Australian climatic and agricultural drought: Payments and policy. Drought Network News 5(3):11–12.

Snidvongs, A. 2006. Vulnerability to Climate Change Related Water Resource Changes and Extreme Hydrological Events in Southeast Asia. AIACC Final Reports, Project No. AS 07. Washington, DC, USA: The International START Secretariat.

Soulé, P.T. 1992. Spatial patterns of drought frequency and duration in the contiguous USA based on multiple drought event definitions. International Journal of Climatology 12:11-24.

Sullivan, C.; Vörösmarty, C. J.; Craswell, E.; Bunn, S.; Cline, S.; Heidecke, C.; Storeygard, A.; Proussevitch, A.; Douglas, E.; Bossio, D.; Günther, D.; Giacomello, A.; O'Regan, D.; Meigh, J. 2006. Mapping the links between water, poverty and food security. Report on the Water Indicators workshop held at the Centre for Ecology and Hydrology, Wallingford, UK, May 16-19, 2005. GWSP Issues in GWS Research No. 1. Bonn, Germany: Global Water System Project, International Project Office. Available at www.gwsp.org (accessed in January 2008).

Thornton, P. K.; Kruska, R. L.; Henninger, N.; Kristjanson, P. M.; Reid, R. S.; Atieno, F.; Odero, A. N.; Ndegwa, T. 2002. Mapping poverty and livestock in the developing world. Nairobi, Kenya: International Livestock Research Institute (ILRI). UNDP (United Nations Development Programme). 2006. Calculating the Human Development Indices, Technical Note 1 in Human Development Report, 2006. UNEP (United Nations Environment Programme). 1992. World Atlas of Desertification. London: Edward Arnold. UNEP. 2008. Africa: Atlas of Our Changing Environment. Nairobi, Kenya: Division of Early Warning and Assessment (DEWA), United Nations Environment Programme. Vörösmarty, C. J.; Federer, C. A.; Schloss, A. L. 1998. Potential evapotranspiration functions compared on US watersheds: Possible implications for global-scale water balance and terrestrial ecosystem modeling. Journal of Hydrology 207: 147-169.

Thornton, P. K.; Kruska, R. L.; Henninger, N.; Kristjanson, P. M.; Reid, R. S.; Atieno, F.; Odero, A. N.; Ndegwa, T. 2002. Mapping poverty and livestock in the developing world. Nairobi, Kenya: International Livestock Research Institute (ILRI).

Tuck, G.; van der Werf, G.; Vayreda, J.; Wattenbach, M.; Wilson, D. W.; Woodward, F. I.; Zaehle, S.; Zierl, B.; Zudin, S.; Cramer, W. 2004. ATEAM Final Report. Potsdam, Germany: Potsdam Institute for Climate Impact Research (PIK). Sheffield, J. 2008. Global drought in the 20th and 21st centuries: Analysis of retrospective simulations and future projections of soil moisture. PhD thesis. Princeton, USA: Princeton University. Sheffield, J.; Wood, E. F. 2007a. Characteristics of global and regional drought, 1950–2000: Analysis of soil moisture data from off-line simulation of the terrestrial hydrologic cycle. Journal of Geophysical Research 112: D17115. doi:10.1029/2006JD008288.

UNDP (United Nations Development Programme). 2006. Calculating the Human Development Indices, Technical Note 1 in Human Development Report, 2006.

UNEP. 2008. Africa: Atlas of Our Changing Environment. Nairobi, Kenya: Division of Early Warning and Assessment (DEWA), United Nations Environment Programme.

UNISDR. 2002. United Nations International Strategy for Disaster Reduction. Living With Risk: An Integrated Approach to Reducing Societal Vulnerability to Drought, United Nations, Geneva. http://www.unisdr.org/eng/task%20force/tf-disc-group1-eng.htm

Vicente-Serrano et al., (2012) Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems. Applied Geography 34 (2012) 471-486

Vicente-Serrano SM, Beguería S, Gimeno L, Eklundh L, Giuliani G, Weston D, El Kenawy A, López-Moreno JI, Nieto R, Ayenewh T, Konte D, Ardö J, Pegramj GGS (2012) Challenges for drought mitigation in Africa: The potential use of geospatial data and drought information systems. Applied Geography 34 (2012) 471-486

Vogt, J. and F. Somma (eds). 2000. Drought and Drought Mitigation in Europe. 318 pp. Kluver Accademic Publishers, London.

Vörösmarty, C. J.; Federer, C. A.; Schloss, A. L. 1998. Potential evapotranspiration functions compared on US watersheds: Possible implications for global-scale water balance and terrestrial ecosystem modeling. Journal of Hydrology 207: 147-169.

Vörösmarty, C.J. 2002. Global water assessment and potential contributions from earth systems science. Aquatic Sciences 64: 328-351.

Vörösmarty, C.J., C. Leveque, C. Revenga (Convening Lead Authors). 2005b. Chapter 7: Fresh Water. In: Millennium Ecosystem Assessment, Volume 1: Conditions and Trends Working Group Report. Island Press. In review

Vörösmarty, C.J., E.M. Douglas, P.A. Green, and C. Revenga. 2005a. Geospatial indicators of emerging water stress: An application to Africa. Ambio. In press.

Vörösmarty, C.J., P. Green, J. Salisbury, and R. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. Science 289: 284-288.

Werick, W.J. and W. Whipple, Jr. 1994. National study of water management during drought: managing water for drought. IWR Report 94-NDS-8. U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources, Alexandria, VA.

Whilhite DA (2005) Drought and water crisis. Science, technology and management issues. Taylor and Francis, New York

White, D.H.; and B. O'Meagher. 1995. Coping with exceptional droughts in Australia. Drought Network News 7(2):13–17.

White, R. P.; Nackoney, J. 2003. Drylands, people, and ecosystem goods and services: A web-based geospatial analysis. Washington, DC, USA: World Resources Institute (WRI). Available at www.wri.org/publication/drylandspeople- and-ecosystem-goods-and-services-web-based-geospatial-analysis (accessed in August 2008). White, W. R. 2005. A Review of Current Knowledge: World Water Storage in Man–Made Reservoirs. FR/R0012. Marlow, UK: Foundation for Water Research.

White, W. R. 2005. A Review of Current Knowledge: World Water Storage in Man–Made Reservoirs. FR/R0012. Marlow, UK: Foundation for Water Research.

Wilhite D.A. and M. Buchanan-Smith. 2005. Drought as hazard: Understanding the natural and social context, pages 3-29 in Drought and Water crises. Science, technology and management issues. Wilhite, D. A. (editor), Taylor & Francis, USA

Wilhite DA (2005) Drought and water crisis: Science, technology and management issues. Taylor and Francis, New York

Wilhite, D. A. (ed.) 2005. Drought and Water Crises: Science, Technology and management Issues. CRC Press, Taylor and Francis Group. 406 pp. Wood, E. F.; Sheffield, J.; Goteti, G. 2003. The Occurrence of Global Drought under Future Climate Scenarios. American Geophysical Union, Fall Meeting 2003. Abstract #H11H-04.

Wilhite, D. A. (ed.) 2005. Drought and Water Crises: Science, Technology and management Issues. CRC Press, Taylor and Francis Group. 406 pp.

Wilhite, D., M.J. Hayes, C. Knutson, N.X. Tsiourtis. 2004. Drought preparedness planning and risk assessment: Terms of reference for MEDROPLAN. Draft no 3.

Wilhite, D.A. 1991. Drought planning: A process for state government. Water Resources Bulletin 27(1):29-38.

Wilhite, D.A. 1995. Developing a precipitation-based index to assess climatic conditions across Nebraska. Final report submitted to the Natural Resources Commission, Lincoln, Nebraska.

Wilhite, D.A. 1997. State actions to mitigate drought: lessons learned. Journal of the American Water Resources Association 33(5): 961-968.

Wilhite, D.A. 2000. Drought: A Global Assessment (Volume I). Routledge Publishers, London, UK.

Wilhite, D.A. and O. Vanyarkho. 2000. Drought: Pervasive Impacts of a Creeping Phenomenon. In D.A. Wilhite (ed.) Drought: A Global Assessment (Volume I). Routledge Publishers, London, UK.

Wilhite, D.A., M.J. Hayes, C. Knutson, and K.H. Smith. 2000. Planning for drought: moving from crisis to risk management. Journal of the American Water Resources Association 36:697-710.

Wilhite, D.A., M.V.K. Sivakumar and D.A. Wood. 2002. Proceedings of an Expert Group Meeting held September 5-7, 2000, in Lisbon, Portugal. World Meteorological Organization (WMO/TD No. 1037).

Wilhite, D.A.; and M.H. Glantz, 1985. Understanding the drought phenomenon: The role of definitions. Water International 10(3):111–120.

Wood, E. F.; Sheffield, J.; Goteti, G. 2003. The Occurrence of Global Drought under Future Climate Scenarios. American Geophysical Union, Fall Meeting 2003. Abstract #H11H-04.

Yohe G, Malone E, Brenkert A, Schlesinger M, Meij H, Xing X (2006) Global Distributions of Vulnerability to Climate Change, Integrated Assessment Journal, 6:3, 35-44.

Yohe, G. and Tol, R.S.J. (2002). Indicators for social and economic coping capacity-moving toward a working definition of adaptive capacity. Global Environmental Change 12 (2002)25 –40

Zaidman, M. D.; Rees, H. G.; Gustard, A. 2000. An Electronic Atlas for Visualisation of Stream Flow Drought. Assessment of the Regional Impact of Droughts in Europe (ARIDE) Technical Report 7. Wallingford, UK: Centre for Ecology and Hydrology.

Zongxue, X.; Jinno, K.; Kawamura, A.; Takesaki, S.; Ito, K. 1998. Performance Risk Analysis for Fukuoka Water Supply System. Water Resources Management 12: 13-30

9. ANNEX 1: OTHER INTERNATIONAL MAPPING EFFORTS

This annex presents a suite of maps as examples of other international drought mapping efforts.

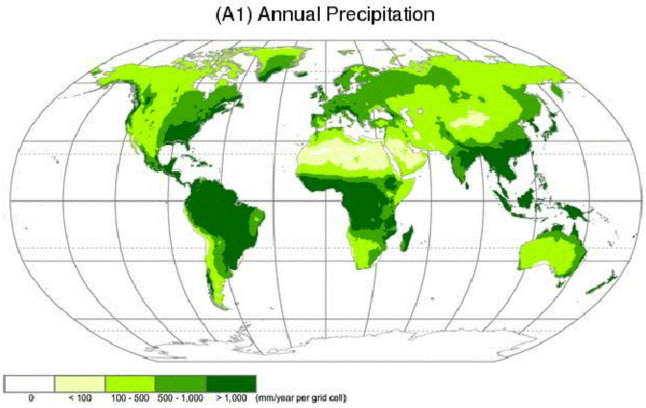


Figure 23 Global annual average precipitation. Source: http://wwdrii.sr.unh.edu

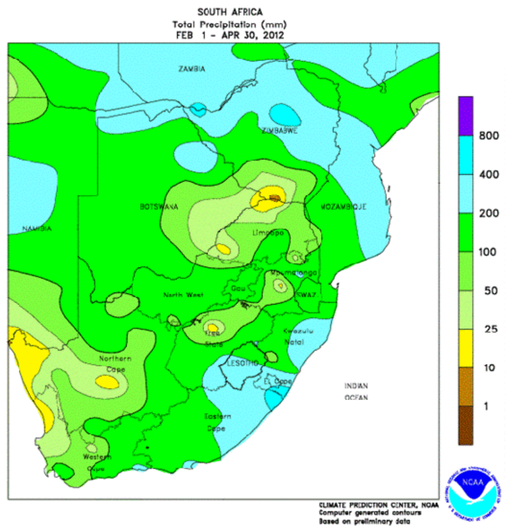
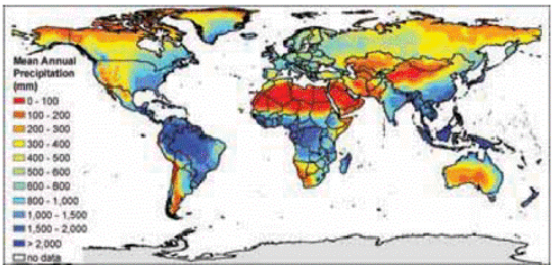
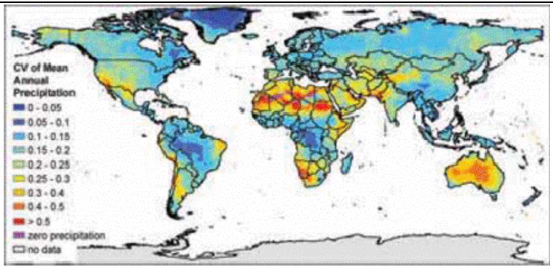


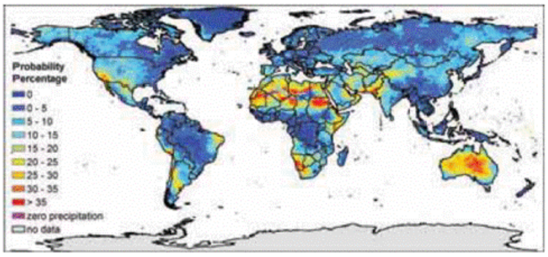
Figure 24 Total average precipitation in southern Africa. Source: NOAA



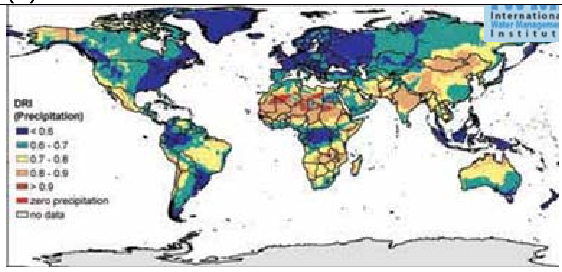
(a)



(b)

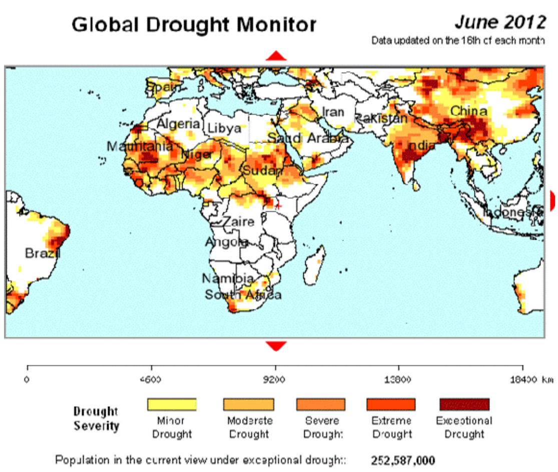


(c)

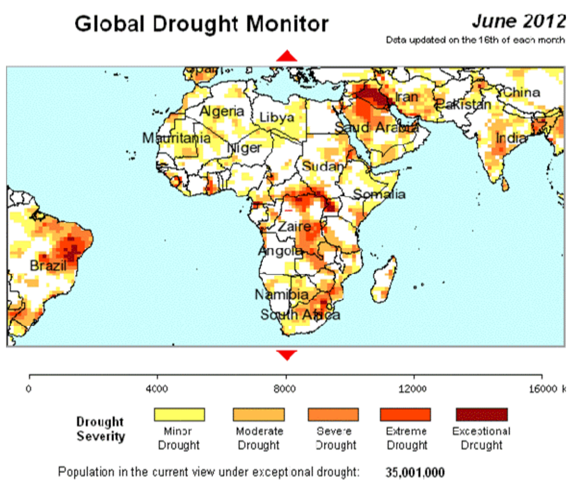


(d)

Figure 25 Global distribution of long-term mean annual precipitation, (b) Coefficient of variation, (c) probability of annual precipitation less than 75% of this long term mean, and (d) drought risk index with respect to monthly precipitation based on the frequency of meteorological (precipitation) drought occurrence and drought intensity (deficit below long-term mean). Source: IMWI, 2009

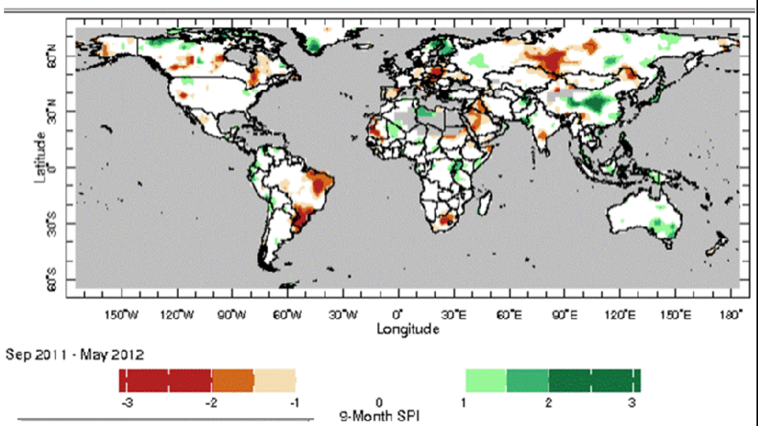


9 month SPI



PDSI

Figure 26 SPI calculations. http://drought.mssl.ucl.ac.uk/sources.html



SPI Values	Category
= 2.00	Extremely Wet
1.50 to 1.99	Severely Wet
1.00 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.00 to -1.49	Moderately Dry
-1.50 to -1.99	Severely Dry
<= -2.00	Extremely Dry

9 month SPI

Figure 27 SPI calculations http://iridl.ldeo.columbia.edu/maproom/.Global/.Precipitation/SPI.html

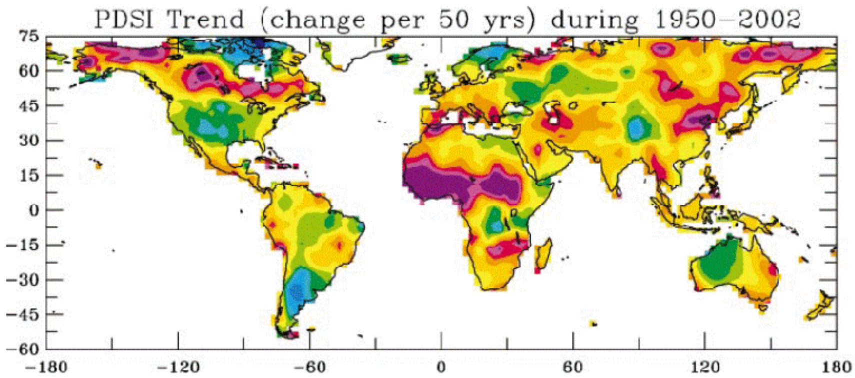


Figure 28 Maps of linear trends of PDSI [change (50 yr), calculated with both precipitation and temperature changes] during 1950–2002. Red (blue) areas indicate drying (wetting). Source: Dai et al., 2004

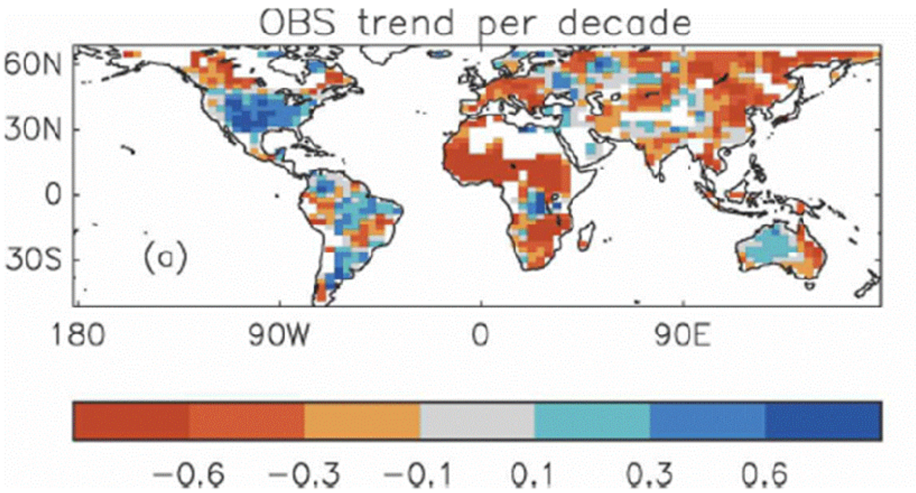


Figure 29 The spatial patterns of the point-by-point trend per decade of the low-pass PDSI filtered to include all time scales greater than 8 y OBS. Source Burke et al., 2006.

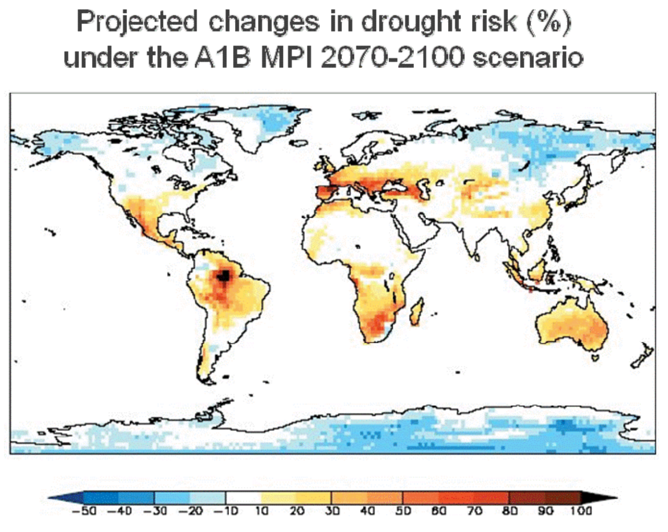


Figure 30 The spatial patterns of the point-by-point trend per decade of the low-pass PDSI filtered to include all time scales greater than 8 y OBS. Source Burke et al., 2006.

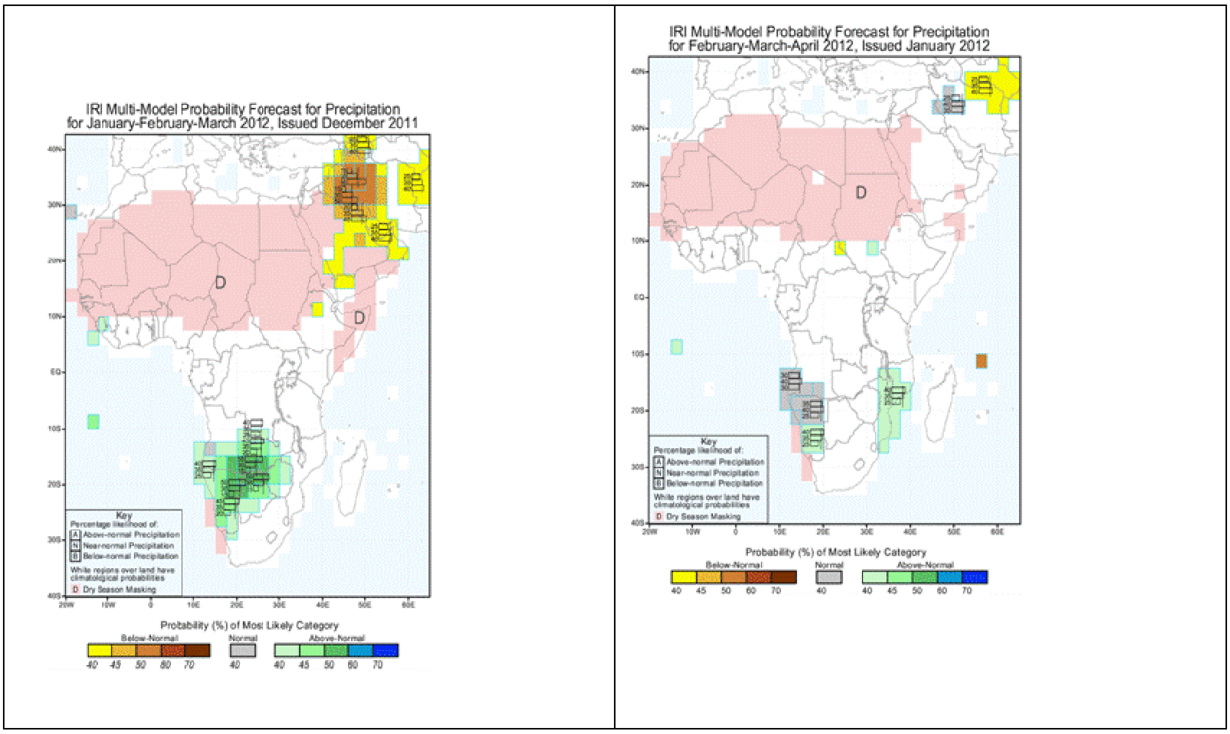


Figure 31 Long-term dynamical weather models from IRI multi-model probability forecast precipitation comparison with standard climate. Source: IRI

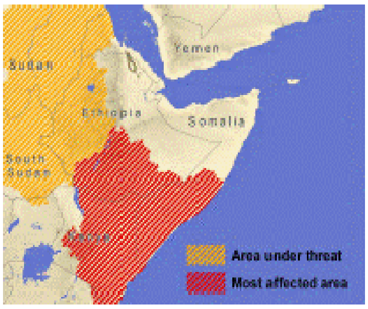


Figure 32 Improved drought monitoring in Africa. Source: http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&obj_id=13740&dt_code=NWS&lang=en

Fig. 4. (A) Average VHI image for the crop season 1983/84 (B) percentage of agricultural area affected by drought (VHIb35) based on (A). The average crop season VHI shows the temporal impact of drought while the percentage of affected agricultural area explains the spatial dimension of the drought.

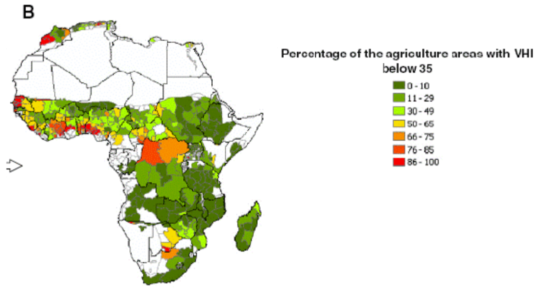


Figure 33 Drought damage in agricultural areas based on earth observation systems indicators. Source: Rojas et al., 2011

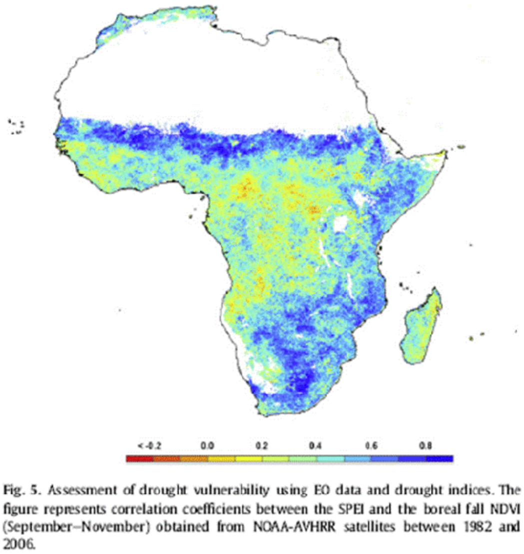


Figure 34 Drought damage in agricultural areas based on earth observation systems indicators. Source: Vicente-Serrano et al., 2011

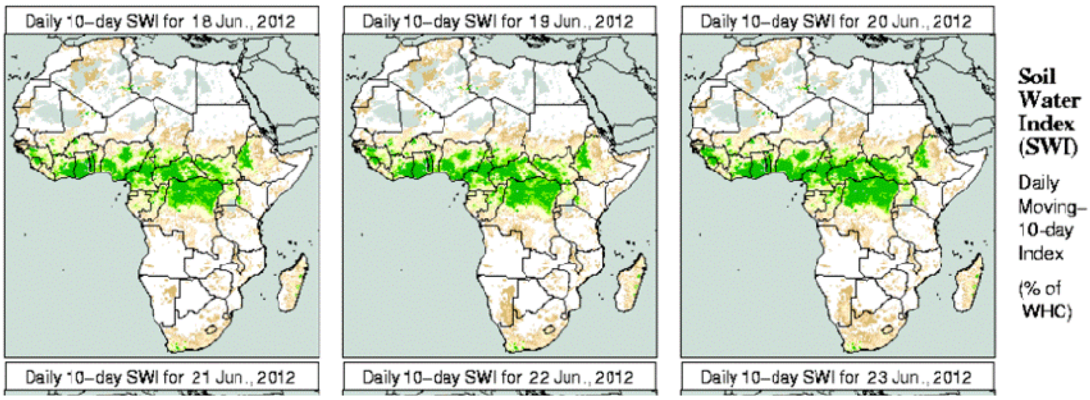


Figure 35 Soil water index used in early warning systems by the FEWS-NET project of the USGS and USAID. http://earlywarning.usgs.gov/fews/africa/web/imgbrowsc2.php?extent=afds

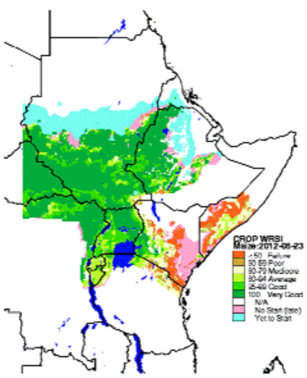


Figure 36 Daily Water Requirement Satisfaction Index (WRSI), 23 Jun 2012. Source: http://earlywarning.usgs.gov/fews/africa/web/imgbrowsc2.php?extent=eewd

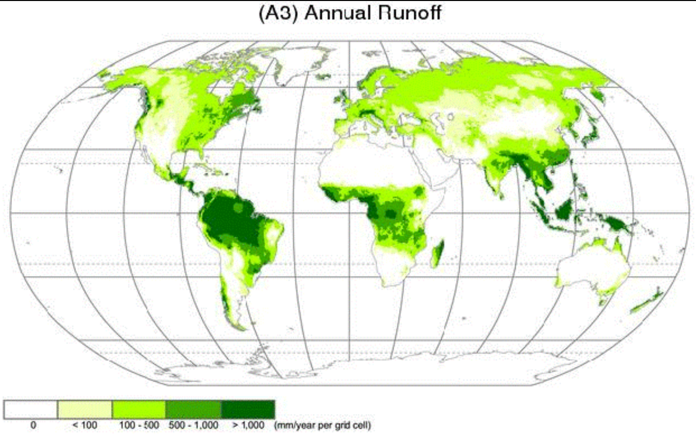


Figure 37 Global annual runoff. Source: http://wwdrii.sr.unh.edu

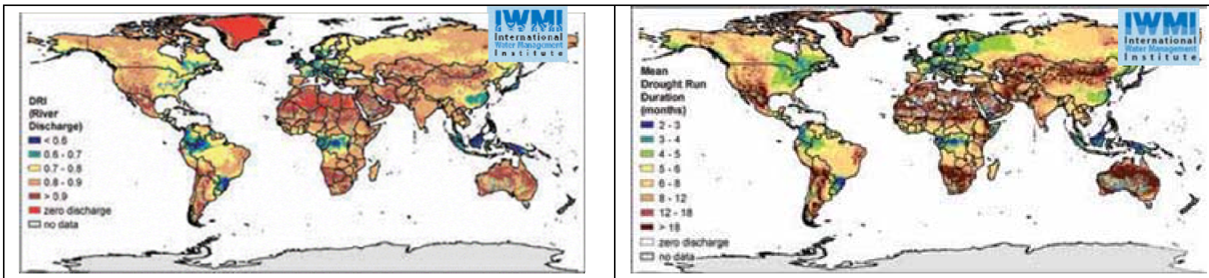
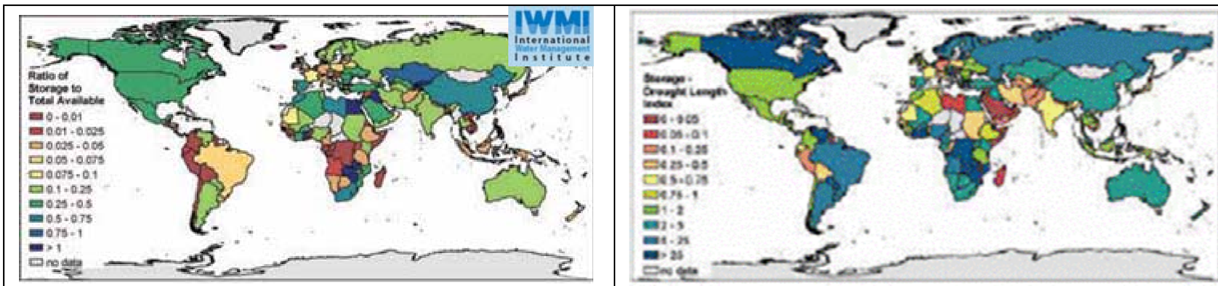
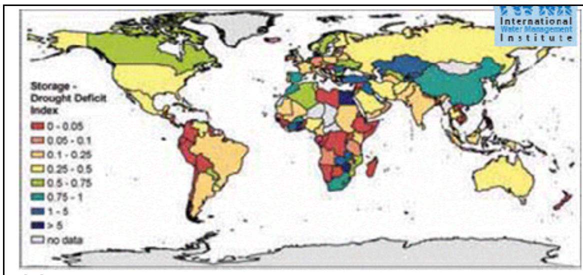


Figure 38(a) Drought risk index respect to monthly river discharge based on frequency of hydrological (river discharge) drought occurrence and drought intensity (deficit below long term mean), (b) Mena drought run duration based on monthly river discharge (sum of durations of all identified drought runs divided by the number of runs). Source: IMWI, 2009



(a) (b)



(c)

Figure 39(a) storage as a proportion of the country total annual renewable freshwater resources, and (b) Storage-drought duration index as the ratio between (i) the duration on months that storage capacity in a country is able to satisfy national water needs and (ii) annual hydrological drought duration calculated relative to the long term mean monthly river discharge, and (c) storage-drought index (how much of the long-term annual hydrological drought deficit is satisfied by existing storage capacity in a country) Source: IMWI, 2009

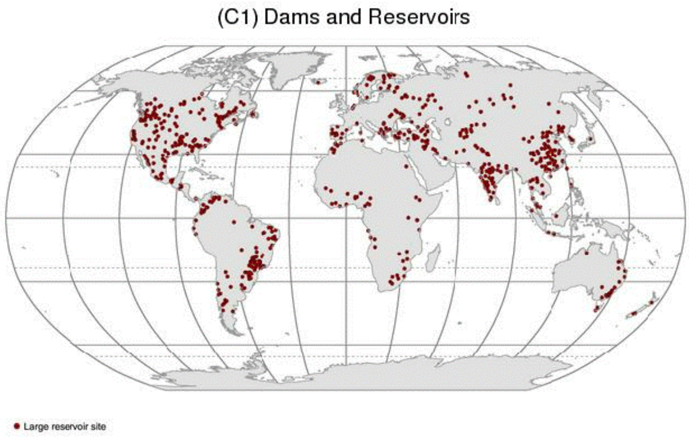


Figure 40 Global dams and reservoirs. Source: http://wwdrii.sr.unh.edu

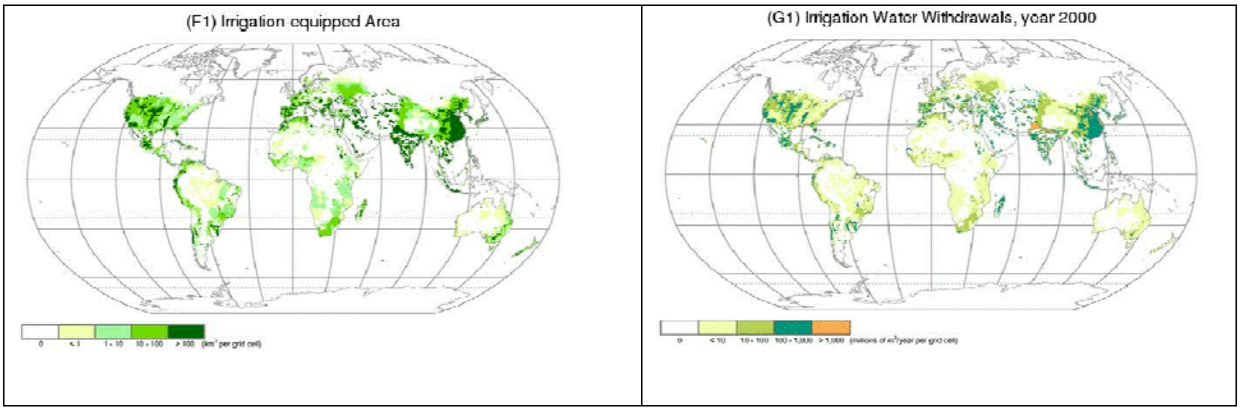


Figure 41 Irrigation equipped area (left) and irrigation water withdrawals (right). Source: http://wwdrii.sr.unh.edu

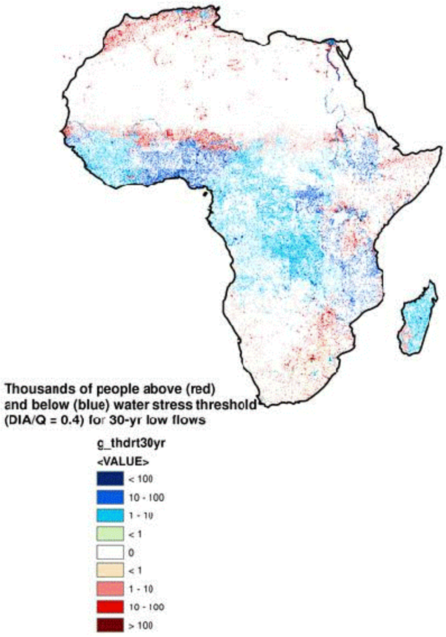


Figure 42 Irrigation equipped area (left) and irrigation water withdrawals (right). Source: http://wwdrii.sr.unh.edu

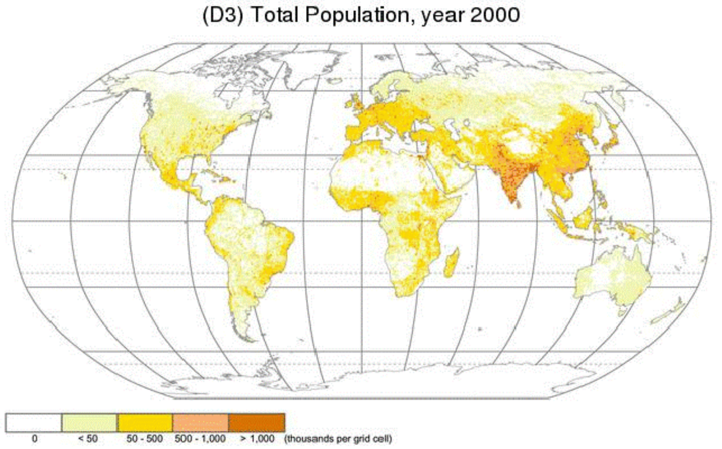


Figure 43 Total population (2000). Source: http://wwdrii.sr.unh.edu

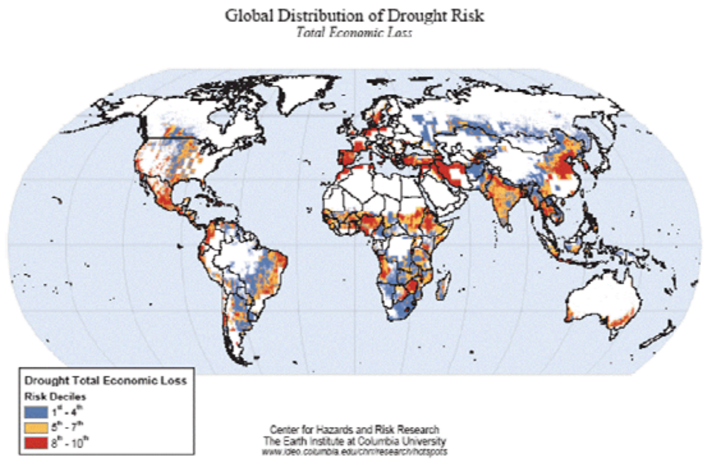


Figure 44 Economic losses due to drought. Source: http://www.columbia.edu

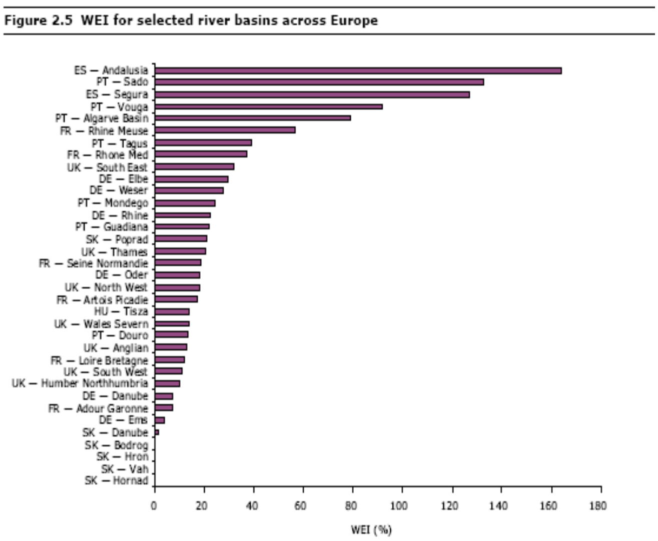


Figure 45 Example of a Water exploitation index (WEI), Indicator of the pressure or stress on freshwater resources (ratio of total freshwater abstraction to the total renewable resource per year), WEI > 20 %, water stress, WEI > 40 %, severe water stress. Source: EEA based on (Raskin et al., 1997)