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

(DEWFORA)

A 7th Framework Programme Collaborative Research Project

Work Package 6

Implementation of improved methodologies

in comparative case studies

DELIVERABLE 6.8 - COMPARATIVE REVIEW OF DROUGHT FORECASTING IN EUROPE AND AFRICA

August 2013

Page intentionally left blank

DOCUMENT INFORMATION

Title	Comparative review of drought forecasting in Europe and Africa	
Lead Authors	FEUP, Uporto	
Contributors	Rodrigo Maia	FEUP, UPorto
	Ana Campos	FEUP, UPorto
Distribution		
Reference	WP6-D6.8	

DOCUMENT HISTORY

Date	Revision	Prepared by	Organisation	Approved by	Notes
	V1	R. Maia, A. Campos	UPorto	R. Maia	
	V2	R. Maia, A. Campos	UPorto	R. Maia	

ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement N°265454.

Page intentionally left blank

EXECUTIVE SUMMARY

This deliverable presents a comparative review of drought forecasting in Europe and Africa. The information presented is based on research where information regarding drought monitoring, forecasting and response systems was collected in different countries of the two continents; through desk study of the DEWFORA deliverables already finished; and also through three questionnaires made by UPorto (Faculty of Engineering). One of these was sent to the main EU institutions responsible for drought management, or directly related to the management of drought, and the other two questionnaires were sent to the DEWFORA case study partners.

Regarding the drought management process, the European and African perspectives present various differences, namely concerning policy and technical capabilities. In European countries there is an increasing effort to implement Drought Management Plants, to involve all the European countries, and to coordinate and facilitate the development and application of drought risk management tools. The continuous improvement of the European Drought Observatory, the possible improvements on drought early warning systems and other initiatives contribute to drought preparedness and to minimising the impacts of drought.

In the case of Africa, some gaps were identified regarding policy issues, since there is no guideline/law, standardised for all countries. Regarding technical capabilities there is also a lack of technical capacity, with insufficient human resources available and inadequate training and financial resources. Different problems were encountered with data collection (inadequate data networks, density of stations, quality, limited availability and high cost of historical data); at organisational level (lack of coordination and interaction amongst institutions), as well as a lack of equipment and technology to generate reliable information, including forecasting systems, models and software.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

ADI - Aggregate Dryness Index

AEMET - *Agencia Estatal de Meteorologia*

AMSR - Advanced Microwave Scanning Radiometer

APA – Environmental Portuguese Agency (*Agência Portuguesa do Ambiente*)

CAMS - Climate Anomaly Monitoring System

CAP - Common Agriculture Policy

CCAM - Conformal-Cubic Atmospheric Model

CDI - Combined Drought Indicator

CILSS - Permanent Interstates Committee for Drought Control in the Sahel *(Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel*)

CPC - Climate Prediction Centre

CRU - Climate Research Unit

CRU - Climatic Research Unit

CS - Case Study

CSIR - Council for Scientific and Industrial Research

DEWFORA - Drought Early Warning and FORecasting to preparedness and adaptation to droughts in Africa

DMCSEE - Drought Management Centre for South-Eastern Europe

DMP - Drought Management Plans

DWD - Deutscher Wetterdienst

ECMWF - European Centre for Medium-Range Weather Forecasts

EDC - European Drought Centre

EDI - Effective Drought Index

EDII - European Drought Impact report Inventory

EDO - European Drought Observatory

EEA - European Environment Agency

EIA - Environmental Impact Assessment

EIB - European Investment Bank

EMA - Egyptian Meteorological Authority

ERS - European Remote Sensing satellite

ET - Evapotranspiration

EUSF - European Solidarity Fund

EVI - Enhanced Vegetation Index

fAPAR - Absorbed Photosynthetically Active Radiation

FDC - Flow Duration Curve

FOEN - Federal office of the Environment

GHA - Drought Monitoring Centre for the Great Horn of Africa

GHACOF - Greater Horn of Africa Climate Outlook Forum

GPCC - Global Precipitation Climatology Centre

GPCC - Global Precipitation Climatology Centre

GPCP - Global Precipitation Climatology Project

GPCP - Global Precipitation Climatology Project

GRDC - Global Runoff Data Centre

GSFC - Goddard Space Flight Center

GTS - Global Telecommunications System

INAG - Water Authority (*Instituto Nacional da Água*)

IPMA – *Instituto Português do Mar e da Atmosfera*

JAXA - Japan Aerospace Exploration Agency

JRC-IES - Joint Research Centre – Institute for Environment and Sustainability

MS - Member States

MWRI - Ministry of Water Resources and Irrigation

NADI - Normalized ADI

NAP - National Action Programme

NASA - National Aeronautics and Space Administration

NDMA - National Drought Management Authority

NDVI - Normalized Difference Vegetation Index

NDVI - Normalized Difference Vegetation Index

NEPAD - New Partnership for Africa's Development

NFC - Nile Forecasting Centre

NFS - Nile Forecast System

NMS - National Meteorological Services

NMSA - National Meteorological Services Agency

NOAA - National Oceanic and Atmospheric Administration

NPP - Net Primary Production

NUTS - Nomenclature of Territorial Units for Statistics

OLR - Outgoing Longwave Radiation

OPI - Precipitation Index

ORMVA - Regional offices for agricultural development (*Offices Régionaux de Mise en Valeur Agricolel*)

PaDI - Palfai Drought Index

PDSI - Palmer Drought Severity Index

PREGEC - *Project de Gestion des Crises*

PRESAO - *PRÉvisions Saisonnières en Afrique de l'Ouest*

RAI - Rainfall Anomaly Index

RAP - Regional Action Programme on drought and desertification

RBMP - River Basin Management Plan

RDC - Regional Drought Committees

RDI - Reclamation Drought Index

RMS - Root-Mean-Square

SADC - Southern Africa Development Community

SARCOF - Southern African Regional Climate Outlook Forum

SARCOF - Southern African Regional Climate Outlook Forum

SDI - Streamflow drought Index

SEA - Strategic Environmental Assessments

SMA - Sudan Meteorological Authority

SNIRH - National Information System for Water Resources (*Sistema Nacional de Informação de Recursos Hídricos*)

SPI - Standardized Precipitation Index

SRAP - Sub-Regional Action Programme

SRI - Standardized Runoff Index

SST - Sea Surface Temperature

SVI - Standardized Vegetation Index

SWIM - Soil and Water Integrated Model

SWSI - Surface Water Supply Index

TCI - Temperature Condition Index

TRMM - Tropical Rainfall Measuring Mission

UN - United Nations

UNCCD - United Nations Convention on Combating Desertification and Drought

USGS - United States Geological Survey

VarEPS - Variable resolution ensemble prediction system

VCI - Vegetation Condition Index

VH - Vegetation Health

WFD - Water Framework Directive

WMO - World Meteorological Organization

WS&D - Water Scarcity and Droughts

1. Introduction

The objective of this deliverable is to develop a comparative review of drought forecasting in Europe and Africa. The implementation of the newly proposed methodologies on drought monitoring and early warning systems of selected African river basins is evaluated, in order to increase the African capabilities. A comparative review of these systems can provide guidelines for bilateral improvement of forecasting methods, while emphasizing differences due to the regional concerns and context.

This deliverable is divided in five topics. Section 2 intends to assess drought preparedness and management processes existing in European river basins. Section 3 does the same assessment regarding African river Basins. Section 4 presents a description of the main improvements developed under the scope of DEWFORA project. In section 5 a comparative analysis between European and African perspectives is done, identifying the main similarities and the main needs for improvement in the African case studies. All these analysis are made in terms of drought monitoring, forecasting and response. Finally, in section 6 the main findings and conclusions are presented.

2. State-of-art on Drought Appraisal and Management in European river basins

2.1. Main guidelines

Concern about water scarcity and drought events has grown within the European Union, especially regarding long-term imbalances of water supply and water availability in Europe in the context of climate change. The number and intensity of droughts in Europe has increased, with the number of areas and people affected by drought increasing by almost 20% between 1976 and 2006 (EC, 2012). Figure 1 pictures the main drought events that have occurred in Europe during the last decade, showing that droughts affects all territory and is a recurrent phenomenon, in particular in Southern Europe.

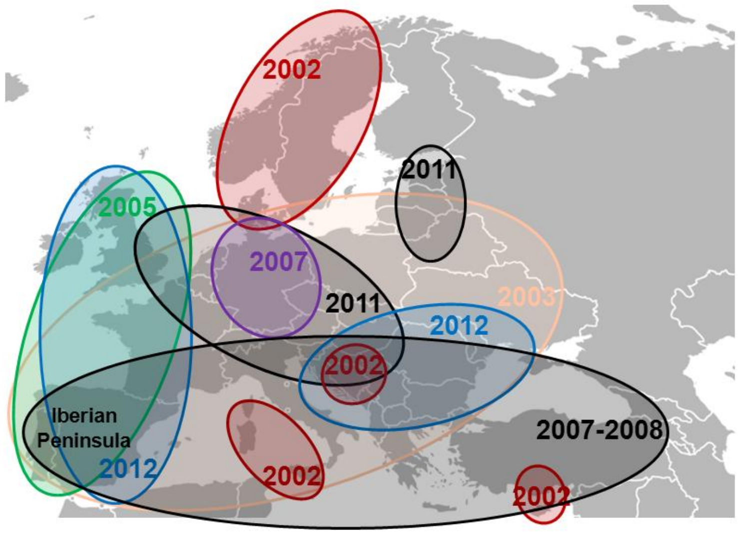

Figure 1. Main drought events in Europe of the last decade. (Adapted from EEA, 2012)

Furthermore, the effects of water scarcity and droughts could worsen under the potential climate change scenarios, increasing the area and population living under water stress. Changes in precipitation and temperature could cause changes in runoff and water availability, with consequences in water related ecosystems, water availability for crops, as well as population's needs (Estrela & Vargas, 2012). According to (EEA, 2005), the temperature in Europe could rise by 2 to 6 °C this century and the expected impacts include water shortages, more extreme weather, marine species migrations and economic losses.

With regard to European water policy relating to water scarcity and droughts, from December 2000 the primary water management legislative act is Water Framework Directive (WFD). This Directive is applied in all current 28 European Union (UE) countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom. The WFD intends to ensure access to good quality water in sufficient quantity for all Europeans, and to ensure the good status of all water bodies across Europe. In this directive, droughts are referred in different parts, and the main objective is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater, in order to mitigate the effects of both floods and droughts, among others. Also, the WFD establishes the possibility of supplementing River Basin Management Plans (RBMPs) with detailed programmes and plans to deal with particular aspects of water management. In this case, Drought Management Plans (DMP) can be considered as relevant additional tools to cope with the effects of prolonged droughts and ensure the WFD's implementation (Estrela & Vargas, 2012). On the other hand, in the RBMP the declaration of drought situations must be defined, including the adoption of adequate indicators and measures. The RBMP should also summarize the effects of droughts and some measures already applied (Estrela, 2006). Finally, RBMP must also take into account the future climate change impacts to help optimising the efficacy of measures that are adopted (EC, 2007).

Moreover, several actions have been under development in Europe since 2006, regarding Water Scarcity and Droughts, being the main guidelines having been defined in a Communication on Drought & Water Scarcity to the European Commission (COM(2007) 414), presented in 2007. The Commission's Communication focuses on the full implementation of the Water Framework Directive and identifies additional policy options that could be implemented to address Water Scarcity and Droughts (WS&D) effects, namely:

- Putting the right price tag on water;
- Allocating water and water-related funding more efficiently
- Improving drought risk management;
- Considering additional water supply infrastructures;
- Fostering water efficient technologies and practices;
- Fostering the emergence of a water-saving culture in Europe;
- Improving knowledge and data collection.

Regarding the improvement of drought risk management the directive promotes the development of:

- drought management plans;
- a drought observatory;
- early warning systems.

Although there is no policy focusing solely on drought, many approaches and activities are currently on-going in Europe to monitor and manage drought, water scarcity and desertification risk, with the priority to move towards a water-efficient and water-saving economy. In fact, several EU countries are already monitoring drought or developing regional or national Drought Management Plans, as pictured in Figure 2. Cyprus also has a Drought Management Plan, although it is not represented in the map.

Figure 2. Characterization of the European member states situation in terms of drought management. (Based on: EEA, 2009)

On the other hand, at EU level, various initiatives related to droughts are being implemented by different agents, centres and networks, such as:

- Joint Research Centre – Institute for Environment and Sustainability (JRC-IES);

- Drought Management Centre for South-Eastern Europe (DMCSEE);
- European Drought Centre (EDC);
- European Expert Group on Water Scarcity and Drought;
- Euro-Mediterranean Information System on know-how in the Water sector (SEMIDE/EMWIS);
- European Environment Agency (EEA);
- etc.

The supported activities deal with different aspects like drought observation and forecasting, indicators' based information collection and dissemination, impact and risk assessments, development of DMPs, development of policy framework, etc. Additionally, the inter-linkages are significant to improve drought preparedness and management, hence a good framework for cooperation, clear definition of roles and efficient joint use of information is still vital (EEA, 2009).

Taking into account the actions promoted for the improvement of drought risk management (COM(2007), 414), a prototype of the European Drought Observatory (EDO) has been further developed, since 2007, providing the continuous monitoring of drought indicators across Europe and displaying these on a map server. All indicators cover the entire European continent and are presented as actual data and as deviation from the expected long-term average. In 2010, the first tests for meteorological drought forecasting were performed and the first interoperability arrangements set up with regional, national and local services including the Drought Management Centre for South East Europe, the Spanish Observatory for Sustainability and the Ebro River Basin Authority.

The most recent (2012, 4th) follow up report of European Commission (EC, 2012), presents the results of the measures favoured in the 2007 Communication on Water Scarcity and Drought so far in EU Member States (MS). In this context, Table 1 summarises the assessment carried out.

Table 1. EU level summary of the achievements of the 2007 Communication on Water Scarcity and Droughts.

Policy area	Sub-policy area	Initiatives been undertaken
Putting the right price tag in water		In 2008 MS were recommended to develop a water tariff policy by 2010, in line with the requirements of the EU WFD. Very limited initiatives have however been taken by MS in this field.
Allocating water and	Improving land-use	Many initiatives were taken at the EU level aimed at

Policy area	Sub-policy area	Initiatives been undertaken
water-related funding more efficiently	planning	improving land use planning, especially in the context of the set of legal proposals designed to make the Common Agriculture Policy (CAP) post 2013 a more effective policy; other sectors of intervention include biofuels and climate change adaptation (National Climate Change Response - White Paper).
	Financing water efficiency	Several initiatives have been taken to incorporate financing to water savings in EU policies (e.g. Regional and Cohesion Funds, CAP and legal proposals for direct payments). Moreover, the European Investment Bank (EIB) adopted a new lending policy for the water sector
Improving drought risk management	Developing drought management plans	The objectives of the initial supporting action have been met to some extent. Whereas a good progress has been achieved both at EU and MS levels.
	Developing an observatory, an early warning system on droughts and the EUSF	Good progress was made so EDO is to become fully operational by 2012. However, the European Solidarity Fund (EUSF) is not well deployed to face droughts.
Considering additional water supply infrastructures		The objectives have been met since all the MS that replied to the questionnaire of 2008 to 2010 indicating enactment of legislation/regulations, Environmental Impact Assessment (EIA) studies, and for some, application of Strategic Environmental Assessments (SEA) on new water supply infrastructure plans
Fostering water efficient technologies and practices		The focus of policies and response actions aimed at improving irrigation systems and strategies mainly focusing on technical measures aimed at improving techniques and practice.
Fostering the emergence of a water-saving culture in Europe		Despite a number of activities launched at the EU level, and fully acknowledging the indirect impacts on water use achieved by the Ecodesign label of energy related products, no labeling or certification scheme is directly related to water. In addition, attempts to initiate a water scarcity related scheme in the framework of the European Alliance on c have not been further pursued. Certification and labeling schemes based on good water stewardship are currently being developed and applied in a wide range of industry driven initiatives
Improve knowledge and data collection	A water scarcity and drought	Efforts taken at EU level (GMES services, WSDiS, EEA WQ Waterbase, JRC EDO, Water Accounts, Research and Regional

Policy area	Sub-policy area	Initiatives been undertaken
	information system throughout Europe	programmes) are all concurring in creating a wide and reliable information base. Progress towards the development of common indicators has been made through the EEA, JRC, etc.
	Research and technological development opportunities	Major research efforts which have been promoted and financed at the European level

It can be concluded that although a growing concern has been expressed throughout the European Union regarding water scarcity problems and drought events, and some efforts have been made to address these problems at different decision-making scales, these efforts are still considered to be insufficient and this could threaten the sustainable management of water resources and of aquatic ecosystems in Europe (EC, 2012).

In fact, in the report of the European Commission reference is made to there still being a gap on "the coherence in response particularly at the EU level, calling for a need to a coherent methodology for assessing Europe's vulnerability to drought and water scarcity and to identify environmental, social and economic co-determinants of drought impacts", (EC, 2012).

The report also mentions that:

- The development of Drought Management Plans has progressed but their implementation as well as their integration with RBMPs and other planning documents remains limited;
- EU wide drought indicators are now available on a preliminary basis for precipitation, soil moisture, vegetation response and a combined drought indicator targeted to agricultural drought;
- Further developments are required to test and improve the indicator set, to add further data from national and river basin level, to test and implement medium to long range drought forecasting and to perform hazard and risk analysis.

2.2. Assessment of situation on drought preparedness on the European countries

The evaluation of European capabilities was made taking into account research work, which envisaged the collection of information regarding drought monitoring, forecasting and response systems. In this context some reports of EU projects like Drought R&SPI and Medroplan were analysed, and some other information for Europe in general (e.g. Horion et al., 2012 by JRC).

Additionally, a questionnaire, entitled “Performance Assessment on Drought Monitoring, Forecasting and Response in Europe”, was made by UPorto (Faculty of Engineering) in order to collect specific information at EU level. This questionnaire was sent to the main EU institutions responsible for drought management, or directly related with this issue, for example for: governmental water management divisions, institutions responsible for the collection of meteorological information, among others.

The aim of this questionnaire was; to collect information on the degree of awareness concerning the issue of drought impacts on water resources; to characterize main drought monitoring, assessment and forecasting tools; to identify the main stages of the drought management process; to compile information on potential adaptation and mitigation measures and strategies, as well as on implementation experiences, and to understand the main Climate Change concerns regarding potential impacts on water resources. The structure of the questionnaire is present in the Annex A.

In this section a general view of the performance assessment of European countries on Drought Monitoring (2.2.1), Forecasting (2.2.2) and Response (2.2.3) is presented. The description made is mainly focused on the sources referred above and centred on the following countries: Cyprus, Germany, Greece, Italy, Netherlands, Poland, Portugal, Spain and Switzerland.

2.2.1. Drought monitoring systems

In order to evaluate the status of drought monitoring systems at European level, the research work and, consequently, this section, was developed with the following structure, enabling to identify:

1) sectors that are more vulnerable to drought, due to their dependence on water;
2) type of data regularly collected;
3) drought indices/indicators used for drought monitoring.

For the adequate use of drought adaptation and mitigation measures, drought management should focus on the main water dependent sectors that could be affected by these events. At

EU level the most affected sectors are: Drinking water/Urban water use, Livestock, Agriculture, Hydropower production and Tourism/Recreation.

The usual data collected in support of drought monitoring is: Precipitation, Temperature, Relative humidity, Evapotranspiration, Wind speed, Solar radiation, Soil characteristics, Stream-flow, Water storage in reservoirs, Groundwater storage, Water quality parameters, Soil moisture, Water level/discharge and Some environmental variables (Snow depth, - cover, - water equivalent; Forest soil pressure, etc.).

There are various datasets that provide different types of information for all European countries and in some cases for the world. Concerning drought monitoring there are two types of datasets used: the traditional methods, based on meteorological indices derived from weather stations data; and the remote sensing data which has been used for timely drought detection and impact assessment and in particular in areas where weather stations are sparse or non-existent. Through these datasets it is possible to estimate precipitation totals, vegetation conditions and soil moisture (Horion et al., 2012).

In Europe, different (of those two types of) datasets are specifically used for drought monitoring (Horion et al., 2012):

(1) Meteorological data measured at weather stations - available through:

- Global Precipitation Climatology Centre (GPCC)

The GPCC is operated by the Deutscher Wetterdienst (DWD) under the auspices of the World Meteorological Organization (WMO) and provides a global analysis of monthly precipitation on Earth's land surface based only in situ rain gauge data. The GPCC products are available in a monthly basis at the spatial resolutions ranging from 1.0° x 1.0° to 2.5° x 2.5° (decimal degrees); non real-time products are also available in 0.5° x 0.5° resolution.

- Global Precipitation Climatology Project (GPCP)

The GPCP is produced at National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and is a mature global precipitation product that uses multiple sources of observations: data from over 6000 rain gauge stations and satellite observations. These have been merged to estimate monthly rainfall on a 2.5° x 2.5° global grid from 1979 to the present.

- ERA-Interim

ERA-Interim is the latest global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). The forecasts of daily precipitation totals are available at the model resolution of 0.7 degrees (about 75km) by arrangement with ECMWF through the Meteorological Archive and Retrieval System, or through the ECMWF public Data Server with a degraded 1.5° resolution.

– Climate Research Unit (CRU)

The CRU product is a 0.5° gridded dataset of monthly terrestrial surface climate variables derived for the period of 1901–00 and updated to 2006 (in preparation). Primary variables (precipitation, mean temperature, and diurnal temperature range) are interpolated directly from station observations. The CRU is part of the School of Environmental Sciences, University of East Anglia.

– Tropical Rainfall Measuring Mission (TRMM)

The TRMM is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) and was designed to measure rainfall for weather and climate research, in particular to improve understanding of precipitation structure and heating in the tropical regions of the earth. The “TRMM and other satellites/sources” (3B-43) precipitation estimate is one of the operational products of TRMM. It intends to produce the best-estimate precipitation rate and root-mean-square (RMS) precipitation-error estimates. These gridded estimates are on a calendar month temporal resolution and a 0.25° x 0.25° spatial resolution global band extending from 50°S to 50°N latitude.

– JRC MARS

The MARS unit of the JRC maintains a database that includes daily precipitation observations from rain gauge stations throughout Europe communicated via the Global Telecommunications System (GTS). The database comprises approximately 5000 stations with historical records of various lengths.

– E-OBS

The E-OBS daily gridded precipitation datasets were generated as part of the EU-FP6 project ENSEMBLES and by the data providers in the ECA&D project. The precipitation is based on daily station observations communicated via the GTS and stations provided by agreement with several National Institutions. The daily station data are interpolated to two regular grids with

0.25° x 0.25° and 0.5° x 0.5° spatial resolutions. The product is available only for Europe from 1950-present with a time lag of approximately 2-months.

(2) Soil moisture data

– Modeled soil moisture

The soil moisture has been estimated through hydrological models. These are representations of the hydrological cycle that take into account several input variables and processes, such as: precipitation (rain/snow); land surface interception, direct runoff, and infiltration; evapotranspiration; land use/ land cover; topography; and others. The temporal resolution is hourly to 6-12 hourly for flood modelling and daily to monthly for water balance estimation. For operational drought assessment and soil moisture monitoring in Europe, the JRC uses the LISFLOOD hydrological rainfall-runoff model. The drought products from LISFLOOD simulations used at the JRC are low flow estimates (applied to climate change scenarios) and soil moisture estimates (i.e. soil moisture anomaly and soil moisture forecasts (medium-range)), provided daily at the 5 km spatial resolution.

– Remote sensing derived soil moisture

Remotely sensed soil-moisture products that can be used for drought monitoring are derived from sensors like the Advanced Microwave Scanning Radiometer (AMSR-E), the European Remote Sensing satellite (ERS) scatterometer, and visible and thermal images from the METEOSAT satellite.

(3) Remote sensing data on the condition of the vegetation

– AVHRR, VEGETATION and ATSR/AATSR

Low spatial resolution sensors provide long time-series of NDVI (Normalized Difference Vegetation Index), offering the best opportunities for long-term studies. NDVI data obtained from these sensors have been used either for land cover mapping or for deriving biophysical indicators, such as Net Primary Production (NPP). Thermal bands available on AVHRR and ATSR/AATSR have also been used for fire detection, despite some technical limitations due to their low saturation temperature.

– MODIS and MERIS

MODIS and MERIS are characterized by the extended geographical coverage, medium spatial and higher spectral resolutions, and equally high temporal resolution and have opened new perspectives to improve drought monitoring studies based on remote sensing data at the regional to continental scales. MODIS data have been acquired since 1999 with maximum spatial resolution of 250 m and 1 day revisit time. MODIS data have been widely used in recent studies for drought assessment at the regional scale. Several derived products can be relevant for drought assessment, including: surface reflectance in the VIS-NIR-SWIR spectral range; vegetation indices (NDVI, Enhanced Vegetation Index - EVI and Normalized Difference Water Index - NDWI); LAI/ Absorbed Photosynthetically Active Radiation (fAPAR); Net Primary Production (NPP); Evapotranspiration (ET).

Concerning the existence of drought monitoring systems in EU member states, and linking with the use of drought indeces all countries have developed a drought monitoring system (Acácio *et al.*, 2013). The exception is Switzerland, where no formal drought monitoring system is operating,.

The data collected and above referred may be used to estimate drought indices. Drought monitoring depends on indices to detect the onset of drought conditions and their evolution, as well as on thresholds to activate drought responses, including the exchange of information between scientists and decision makers as well as with the general public. Thus, these drought indices allow the quantitative assessment in terms of drought intensity, spatial extent and frequency, and consequently operational drought characterisation and monitoring. According to the information collected (Acácio *et al.*, 2013; and responses to the questionnaire), the commonly used drought indeces at EU level are: Standardized Precipitation Index (SPI), Effective Drought Index (EDI), Flow Duration Curve (FDC), Palmer Drought Severity Index (PDSI), Reclamation Drought Index (RDI), Palfai Drought Index (PaDI), Wet Period Runoff Index, Hydrologic Years Runoff Index, Monthly Regime Index, Dams Storage Index, Streamflow, % of soil water content, Groundwater tables, Standardized Runoff Index (SRI), Stored volume in reservoirs, Piezometric levels in aquifers, Areal rainfall, Evaporation surplus and Water quality parameters.

The European Drought Observatory currently produces several indicators for drought monitoring at the EU level. They include Standardized Precipitation Index, at different time scales (SPI-3,-6,-9,-12,-24); Soil Moisture Anomalies (daily, 10-day average); Anomalies in Vegetation vigour (i.e. anomalies of the fraction of Absorbed Photosynthetically Active Radiation - fAPAR) and a Standardized Snowpack Indicator. In addition, a Combined Drought Indicator (CDI, 10-daily) is produced, providing different alert levels targeted to the policy and management level. Additional indicators are produced at the river basin, country or region level. These indicators are produced by the relevant authorities and added to the EDO map server through interoperable mapping services.

2.2.2. Drought forecasting

In what concerns forecasting systems JRC (1) use ECMWF ensemble forecasts for testing the possibilities to obtain meteorological drought indicators with 1 week to 1 month lead time; (2) is introducing deterministic meteorological forecasts into a distributed hydrological model (LISFLOOD) to obtain soil moisture and soil moisture anomalies with up to 7 days lead time.

The EDO is a continuous monitoring and forecasting systems that provides up-to-date information on drought in Europe, managing a series of indicators in order to assess and quantify the occurrence, duration and severity of different types of drought events. On the other hand, EDO also uses deterministic meteorological forecasts to obtain soil moisture and soil moisture anomalies with up to 7 days lead time through a distributed hydrological model. The 7 days forecasts stem from the ECWMF numerical weather forecast system.

On the other hand, the European countries also rely on ECMWF ensemble forecasts for testing the possibilities to obtain meteorological drought indicators with 1 week to 1 month lead time. The set of available data from ECMWF correspond to:

- Atmosphere global forecasts (forecast to ten days from 00 and 12 UTC at 16 km resolution);
- Ocean wave forecasts (forecast to five days from 00 and 12 UTC at 11 km resolution);
- 51-member ensemble prediction system (To day 15 from 00 and 12 UTC, 32 km resolution up to day 10, then 65 km);
- Seasonal forecasts: Atmosphere-ocean coupled model (41-member global forecasts to seven months - System 4, atmosphere: 120 km resolution);
- Reanalysis (Atmosphere: 80 km horizontal resolution, 6 hourly analysis, 12 hour 4D-Var assimilation, 10 days forecasts at 00 and 12 UTC).

Regarding the last two topics, two ensemble forecasting systems are currently operational at ECMWF: VarEPS (variable resolution ensemble prediction system) for medium-range weather forecasting (forecasts out to 32 days) and seasonal forecasting (forecasts out to 7 months).

2.2.3. Drought response

In order to assess the status of drought response at European level, some countries were analysed, and the structure used on the research was focused on the identification of:

1) main stakeholders responsible for drought management process;
2) brief description of the drought management process (interaction between stakeholders);
3) typology of drought measures applied in each country/basin (including drought adaptation and mitigation measures and taking also into account the European Drought Impact report Inventory);
4) existence of Drought Management Plans (already presented in 2.1).

Drought preparedness requires coordination among the stakeholders. The identified authorities that support drought monitoring in each case involves mainly national meteorological services which provide climate data and water management authorities, either at national or river basin scale and governmental departments, Table 2.

Table 2. Institutions and Stakeholders involved in drought management process.

Country	Institutions and Stakeholders responsible for drought management process
Poland	Ministry of Environment National Water Management Board
Germany	German governmental institutions
Greece	Hellenic National Meteorological Service The Ministry of Environment, Energy and Climate Change – Special Secretariat for Water, The Ministry of Rural Development and Food Regional Authorities, Water Supply and Sewerage Companies Agricultural Cooperatives
Cyprus	Water Development Department ---> Ministry of Agriculture, Natural Resources and the Environment ---> Council of Ministers
Netherlands	Royal Netherlands Meteorological Institute (climate data and forecasts) National Water Monitoring Network (water quantity measurements) Rijkswaterstaat (water quantity and quality data, groundwater level data) Water management centre the Netherlands (information centre) National Committee Water Distribution (drought management)
Portugal	IPMA (precipitation and temperature data to calculate SPI and PDSI) APA (Precipitation, streamflow, water storage in reservoirs, groundwater storage, water quality parameters)
Switzerland	Federal Office of Meteorology and Climatology (climate data) Federal Office of the Environment (hydrological data) Swiss Federal Institute for Forest, Snow and Landscape Research (environmental measurements)

Country	Institutions and Stakeholders responsible for drought management process
	Swiss Soil Moisture Experiment - ETH (soil moisture)
Spain - Jucar basin	Jucar River Basin authority (data collection and processing)
Italy - Po basin	Po River Basin authority (data collection and processing)

It is important to refer that regarding Spain and Italy, only one basin was considered for each country, according to the information provided by (Acácio *et al.*, 2013) in Drought R&SPI report. However, the following description of the operation drought management process (Table 3) tries to include both of the countries, and not only the correspondent basins.

Table 3. Operational Drought Management Process.

Country	Operational Drought Management Process
Poland	N/A
Germany	Deutscher Wetterdienst issues drought warnings to governmental authorities. This scientific agency monitors weather and meteorological conditions over Germany.
Greece	The existing general regulation for drought management in Greece is the Greek National Action Plan For Combating Desertification, but it is not in operational use. So far, in case of serious drought phenomena, the responsible authorities collaborate and implement practices in order to face the situation.
Cyprus	Plans and policy proposals are prepared by the Water Development Department, to be submitted to the Ministry of Agriculture, Natural Resources and the Environment and, after approval is secured from the Council of Ministers, then implemented. The institutions involved in drought preparedness and drought management are engaged in different actions for meteorological and hydrological drought preparedness planning and mitigation.
Netherlands	The Water Management Centre provides daily information to users of the Dutch water system regarding water levels, flood risks and (bathing) water quality. In extreme situations, including water shortages, water pollution and the threat of flooding, the Water Management Centre provides advice to the national and regional water authorities about the expected condition of the water. The national and regional departments of the Directorate General of Public Works and Water Management (Rijkswaterstaat) work together in the Water Management Centre and as a result there is better information provision and forecasts.
Portugal	There are two Drought Monitoring Systems in Portugal managed by two different entities: The Drought Observatory and the National Information System for Water Resources. The Drought Observatory ("Observatório de Secas") is coordinated by the Meteorology Institute (IPMA, Ministry Education and Science) and monitors the main climate parameters, namely, precipitation and temperature. The National Information System for Water Resources ("Sistema Nacional de Informação de Recursos Hídricos" – SNIRH) is coordinated and managed by the Water Authority (APA, former INAG, Ministry of Agriculture, Sea, Environment and Spatial Planning) and monitors water resources through a

Country	Operational Drought Management Process
	national network of stations, more specifically regarding river water flows, reservoirs water levels, groundwater levels and river water quality. The occurrence of meteorological droughts is based on calculations of SPI and PDSI averaged for main river basins and for mainland Portugal, and agricultural droughts based on soil water content (%). When a drought situation is detected and declared, a drought commission is constituted, by the Government, in order to ensure drought management.
Switzerland	There is to date no operational Drought monitoring system. However, Switzerland has a dense network of monitoring stations observing related environmental variables including an array of meteorological and hydrological observables. The most important monitoring networks are coordinated under the umbrella of governmental agencies: The "Federal Office of Meteorology and Climatology" (MeteoSwiss) maintains a national network for meteorological variables and the "Federal office of the Environment, FOEN" focuses on hydrological variables. Drought-related information is derived from measurements that are readily available from operational environmental and meteorological monitoring networks. This is currently done in an ad-hoc basis, often by comparing the current conditions to the climatology.
Spain	The main tools available for planning and management drought are: Drought Management Plans, System indicators of hydrological status, contingency plans for urban supply for more than 20,000 inhabitants. On the other hand, Drought Observatory ("Observatorio Nacional de la Sequía") brings together all Spanish water administrations with responsibilities regarding water issues, in order to establish a knowledge, anticipation, mitigation and monitoring center of the effects of drought in the country. Meteorological Drought Monitoring is also made with the information provided by AEMET (Agencia Estatal de Meteorologia).
Italy	For forecasting purposes, the input consists in meteorological data from the European Centre for Medium-Range Weather Forecasts. The weather input feeds a physically based hydrological rainfall-runoff model, the Topkapy model, which has been implemented for the whole river basin and calibrated over each available gauging station. In the specific case of Po river basin an early warning system, called "DEWS-Po: Drought Early Warning System for the Po River" has been developed to manage at a first time flood's events, and afterwards it was upgraded with tools to enable its use along with drought events.

In the context of drought response, the implementation of mitigation and adaptation measures should be distinguished as: drought mitigation is the reduction of the effects of drought impacts that effectively occurred, through economic compensation or implementation of emergency measures to ensure a minimum level of water supply, for example; drought adaptation is a process of being able to avoid or to overcome potential problems in a drought condition. It refers to changes in processes, practices, and structures to moderate potential impacts of future droughts.

On this topic, the most important adaptation and mitigation measures and strategies that should be implemented in European countries are:

Drought adaptation measures

- Reinforcing the use of rainfall harvesting, water cisterns, fog collection, etc.;
- Groundwater recharge;
- Demand delivery scheduling in pressurized systems;
- Selection of crop varieties according to their tolerance to water stress conditions and dry conditions;
- Tillage and land-forming practices (soil management);
- Improving surface irrigation measures;
- Adopting water prices that induce farmers to save water and to irrigate during night;
- Farmers involvement in decisions to change delivery schedules dictated by limited supply;
- Terracing (maximization of soil infiltration);
- Use of small dams (farm ponds), also to increase aquifer recharge.

Drought mitigation measures

- Definition of strategic water reserves for priority uses;
- Water conservation recommendations for farmers;
- Control of water allocation in irrigation areas;
- Activation of emergency plans in water supply systems;
- Use of non-conventional water resources;
- Adaptation of reservoirs exploitation rules;
- Increase of water quantity and quality monitoring.

Additional to the implementation of drought mitigation and adaptation measures, drought management requires a good knowledge of how to implement/apply this information to each reality. Therefore, it is important that drought related impacts' are fully and systematically characterized and recorded, for every drought situation, in order to improve drought impact and vulnerability assessments and contribute more effectively to the reduction of economic losses and societal stress during drought situations. Thus, the establishment of a database or 'inventory' of drought impacts, i.e. reported records of a variety of drought impacts is a crucial tool. In this context, the European Drought Impact report Inventory (EDII) developed as part of the EU FP7 project Drought R&SPI (Fostering European Drought Research and Science-policy Interfacing) aims to collect and build a database of past drought impacts in Europe reported by various sectors. Although the project is based on specific case studies, the EDII is available for drought impacts records collection for every EU countries. The goal is to obtain an improved knowledge on the relation between indicators and impacts in different geoclimatic regions in Europe that will help a regional or sector-specific interpretation of drought vulnerability and risk. Impact information shall be (Stahl et al., 2012): classified into pre-defined impact categories; referenced temporally and spatially; complemented with additional reported impact information including drought response measures where applicable.

The EDII is based on reports of drought impacts. Type of source - report, journal article, book, thesis, newspaper, website, etc. - and reference with Author, Year, Title, website (if applicable), etc. are the required information to be entered into the database. Regarding the impact information, it includes minimum information:

- Geographic location of reported impact with options to refer to different levels of the European Union NUTS (The Nomenclature of Territorial Units for Statistics) regions standard, river or reservoir names, and other landmarks;
- Time of reported impact (at least the year) and its link to a major known drought event;
- Impact category and type according to pre-defined lists;
- Associated secondary impacts, response and mitigation measures, and other relevant information that may be available.

Overall, 858 entries of drought impacts have been added to the database, and the countries with more entries are Germany, Portugal, Netherlands and Spain. Reports about impacts on “Agriculture and Livestock Farming” and “Freshwater Ecosystems” are the most frequently reported impacts in the preliminary database (status 31. Aug. 2012). Furthermore, impacts on “Water Quality” made up a large proportion during the 2003 Central European drought, whereas impacts on “Water Supply” constituted a large proportion in the 2004-2007 Iberian drought event. Impacts on “Energy and Industry” were also common to both events with a considerable number of database entries.

Figure 3 shows a timeline of the 16 (out of the 63 events), which have more than 5 impacts entries in the database.

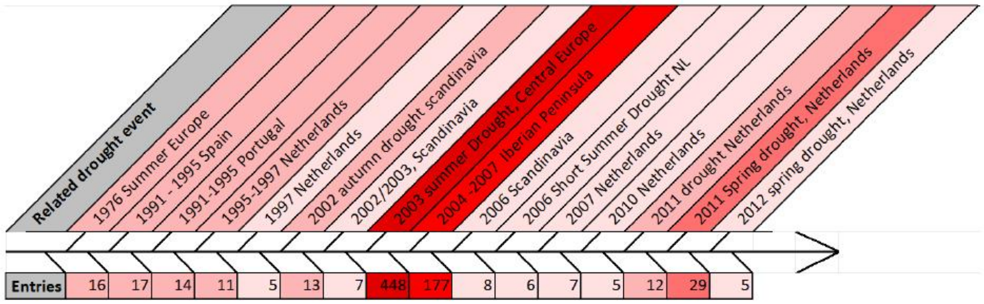

Figure 3. Timeline of drought events to which > 5 entries are related. Darker colour denotes a larger number of related entries – status 31 August 2012. (Based on Technical Report No. 3 of Drought R&SPI, 2012)

The largest number of impact entries was made for the 2003 summer drought event that affected large parts of Europe and for the 2004-2007 multi-year drought event on the Iberian Peninsula. In these cases, impacts are therefore already well documented in the database.

3. State-of-art on Drought Appraisal and Management in African river basins

The objective of this chapter is to assess the performance on drought appraisal and management in Africa river basin. For that, information on the capacities regarding drought monitoring, forecasting and response systems was collected from the main case studies within the DEWFORA project.

3.1. Main guidelines

Drought is one of the most important natural disasters in Africa and drought events continue to threaten the livelihoods of millions of people in the African continent. The impact of drought is the most costly event in African countries. Africa's economies depend on climate-sensitive sectors, such as rain fed agriculture, and have a high dependence on natural resources. African economies are impacted by poor infrastructure and damaging disease issues. These facts contribute to the high vulnerability of the continent to the impacts of droughts. The most severe consequence of drought is food insecurity including devastating famines, but also water scarcity, epidemics and land degradation are similarly relevant (UN, 2007; Vicente-Serrano et al., 2012). These impacts result also from the low resilience in Africa and limited capacities to mitigate drought effects.

Linked to natural hazards in Sub-Saharan Africa, drought and floods account for 80 percent of loss of life and 70 percent of economic losses. In 2011 a drought event in Zimbabwe resulted in a 45 percent drop in agricultural production. Consequently, the number of people affected is very high: in 2000, at the time of the Horn of Africa's drought, 3.2 million Kenyans were dependent on food aid, and malnutrition reached 40 percent of the population, representing more than 3 times the normal level. The drought of 2002–03 in Southern Africa resulted in a food deficit of 3.3 million tonnes, with an estimated 14.4 million people in need of assistance. In 2005 many African countries faced food shortages due to the combined effects of severe droughts and desertification (the most affected countries including Ethiopia, Zimbabwe, Malawi, Eritrea and Zambia, a group of countries where at least 15 million people would go hungry without aid); more recently, in 2011 in Somalia, a severe drought has caused 10 million people in need of humanitarian aid, more than 2 million children malnourished and in need of lifesaving action, and more than 380,000 refugees living in camps of Kenya (UN, 2007; Vicente-

Serrano et al., 2012). In addition, two thirds of Africa is classified as deserts or drylands, mostly concentrated in the Sahelian region, the Horn of Africa and the Kalahari in the south.

The drought events per country from 1970 to 2004 within Sub-Saharan Africa (i.e, all African continent expect North Africa) are presented (named countries) in Figure 4.).

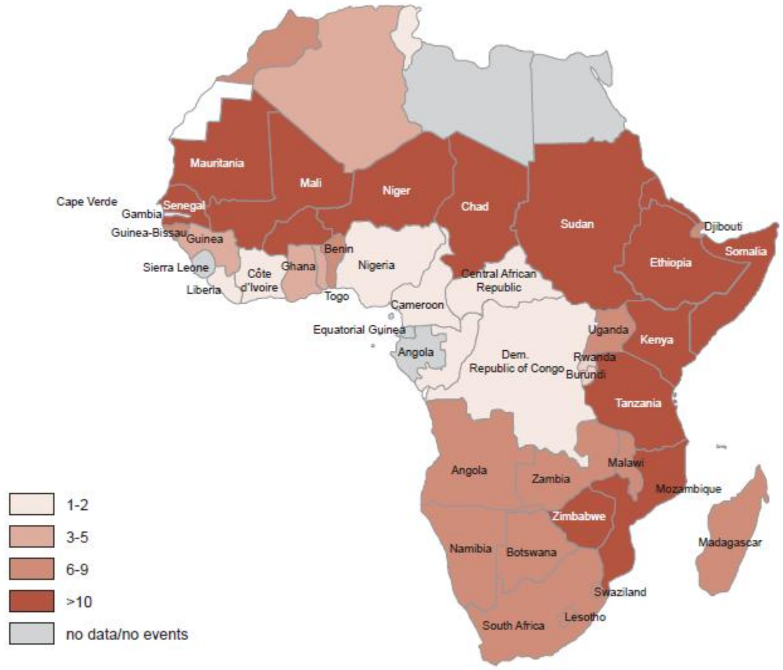

Figure 4. Drought events per country from 1970 to 2004 within Sub-Saharan Africa.
Source: Adapted from Noojin, Leah 2006, "Factors that influence famine in Sub-Saharan African Countries"

The Sahelian drought and famine of 1968 to 1974 had horrific combined effects and impacts of desertification and drought - hundreds of thousands of people and millions of animals died. This situation was a major incentive for the establishment of the United Nations Convention on Combating Desertification and Drought (UNCCD) due the devastating impact on the ecologically vulnerable Sahel region (Mishra & Singh, 2010). More recently, in 2010/2011 in Horn of Africa, the devastating impacts call for urgent attention regarding policies and actions at global, national and regional level and demonstrate that monitoring and forecasting both the time length and geographical extension of droughts is relevant to increase drought preparedness (UN, 2007; Dutra *et al*., 2012).

The related progress demonstrated by African countries during the last years is focused on the implementation of the United Nations Convention to Combat Desertification and on the relevant programs of New Partnership for Africa's Development (NEPAD). UNCCD was adopted in 1994 and its objective is to "combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification, particularly in Africa". The UNCCD – in fact, the only legally binding international agreement related to sustainable land management and mitigation of drought effects - provides essential opportunities to combat desertification and droughts, with support from international partners (UN, 2007).

The most relevant actions that are being implemented correspond to the: National Action Programmes to combat desertification (NAPs), which are the overall strategies for specific land and drought-related plans and programs, and also represent significant tools in guiding the implementation, coordination and monitoring of efforts in combating desertification and poverty; Regional Action Programmes on drought and desertification (RAPs); Sub-Regional Action Programmes on drought and desertification (SRAPs). To those add some other programs in environment and agricultural sectors that have been developed. As of April 2007, NAPs had been developed and adopted by 42 African Countries.

3.2. Assessment of the situation on drought preparedness on the African countries

The characterization of existing drought monitoring, forecasting and response procedures in Africa was based on the responses to the Questionnaire made by UPorto (Faculty of Engineering) under the scope of DEWFORA Project for Performance Assessment on Droughts Capabilities of DEWFORA Case Studies (Task 6.6) – Annex B; on DEWFORA deliverables already finished (e.g. Deliverable 2.4 – Gap analysis report on drought monitoring and forecasting systems in Africa, Deliverable 5.3 - Framework for drought warning and mitigation from national to local scale and Deliverable 6.1 – Implementation of improved methodologies in comparative case studies); inputs collaboration of DEWFORA partners; and additional research.

The information in this section is based on the data collected for each African case study (Eastern Nile, Limpopo, Niger and Oum-er-Rbia) and a general view about the performance assessment of these case studies on Drought Monitoring (3.2.1), Forecasting (3.2.2) and Response (3.2.3) is presented.

3.2.1. Drought monitoring systems

In this section the following topics were assessed for each case study:

1) sectors that are more vulnerable to drought, due to their dependence on water;
2) type of data regularly collected;
3) drought indicators used for drought monitoring in each region;

As mentioned in section 3.1, African economies are in many cases dependent on climate-sensitive sectors, such as rain fed agriculture, making African countries vulnerable to drought impacts. In fact, in African countries the most drought affected sector is agriculture.

According to the responses to the Questionnaire made for Performance Assessment on Droughts Evaluation of DEWFORA Case Studies, there is a regular drought monitoring appraisal in all case studies.

Table 4 resumes the typical data collected in DEWFORA Case Studies in support of drought monitoring.

Table 4. Usual data collected for drought monitoring in DEWFORA Case Studies.

Case Study	Data collected
Eastern Nile	Rainfall; temperature; humidity; wind direction and speed; sunshine hours; air pressure; cloud coverage; cloud type and land use data. In some countries, additional information is not collected locally due to the lack of appropriate equipment like upper air station, radar , etc
Limpopo	Rainfall; maximum and minimum temperature; wind speed and direction; relative humidity; sunshine and sun radiation; evaporation; reservoir levels; ground-water table and stream flows.
Niger	Wind speed and direction; temperature; insulation; evapotranspiration; rainfall; flood height; river discharge; flood duration; monitored rainfall; flood extent from satellite imagery; national to regional statistical census; and reservoir and irrigation schemes management information.
Oum-er-Rbia	Precipitation; temperature; wind direction and speed; evaporation; snow cover; stream flows; reservoir levels; groundwater; water supply; soil moisture, soil texture and depth; satellite images; additional information: evolution of forest and rangelands areas, field surveys, length of the agricultural season: food and water availability for livestock; socio-economic data.

The datasets used in African countries for drought monitoring and assessment of drought indicators have been identified, according to the information provided by DEWFORA project (DEWFORA, 2013). These datasets correspond to:

(1) data measured at weather stations and satellite observations:

- by the Global Precipitation Climatology Centre (GPCC);
- by the Climate Prediction Centre (CPC);
- by the Global Precipitation Climatology Project (GPCP);
- by the Global Runoff Data Centre (GRDC).
-

and

(2) modelled/remotely sensed and integrated datasets:

- Conformal-Cubic Atmospheric Model (CCAM) seasonal forecasting system, by the Council for Scientific and Industrial Research (CSIR) in South Africa;
- CAMSOPI, a merged dataset produced by the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Centre (CPC) combining satellite rainfall estimates from the Outgoing Longwave Radiation (OLR) Precipitation Index (OPI) with ground-based rain gauge observations from the Climate Anomaly Monitoring System (CAMS);
- ERA Interim (ERAI);
- ERAI sea surface temperature (ERAI –SST) and HADSST2 sea surface temperature anomaly data sets;
- HydroSHEDS data set (catchment boundaries and rivers).

Drought indices identified for each case study through the data collected and already referred are presented in Table 5.

Table 5. Drought indices used for each case study.

Case Study	Drought indices
Eastern Nile	SPI; Mean Average discharge at El Diem station – Ethiopia and Khartoum station, on the blue Nile – Sudan; Average discharge anomalies over June-July-August-September at El Diem station; Average annual nature flow at High Aswan Dam.
Limpopo	SPI; Dry spells; Reservoir storage; Reservoir inflows and outflows; Reservoirs levels; Ground-water table; Stream flows.
Niger	Rainfall Anomaly Index (RAI); SPI; Discharge/Water Level Anomaly Index; % from the flow/water level duration curve; Mean annual minimum flow/water level; Base flow/water level indices; Standardized discharge/water level index; Hydrological requisite and Fodder production indices for the main vegetation formation.
Oum-er-Rbia	Deviation from normal precipitation; Precipitation deciles; SPI; Surface Water Supply Index (SWSI); Aggregate Dryness Index (ADI); Normalized ADI (NADI); Streamflow drought Index (SDI); Vegetal production; Livestock production, food and water availability for livestock; NDVI; Standardized Vegetation Index (SVI); Vegetation Condition Index (VCI); Temperature Condition Index (TCI);

Case Study	Drought indices
	Vegetation Health (VH); Ploughed fields and cereal seedlings situation.

Regarding drought monitoring systems in Africa, some efforts have been made and include: Regional Early Warning System of the Southern Africa Development Community (SADC), Drought Monitoring Centre for the Great Horn of Africa (GHA) and West African Permanent Interstate Committee on Drought Control in the Sahel (CILSS). Although these systems are focused on selected drought-prone areas, they do not cover the all African countries, are not operating in real-time and in some cases are not updated regularly.

3.2.2. Drought forecasting

Through the questionnaire made with the Case Study (CS) partners it was possible to identify the models and tools used for meteorological, hydrological and agricultural drought forecasting, their main inputs, outputs and the lead times of the forecasts made (Table 6).

Table 6. Models and tools for meteorological, hydrological and meteorological droughts forecasting for each Case Study.

Eastern Nile CS	
Model: ETA Model	
Characteristics	State-of-the-art atmospheric model. It has been very successful in regional weather forecast.
Inputs	Initial and lateral boundary conditions from NCEP GCM.
Outputs	Surface pressure, horizontal wind components, temperature, specific humidity, turbulent kinetic energy, cloud hydrometeors.
Lead time	Forecasts up to five days.
Model: MM5 Model	
Characteristics	Designed to simulate or predict mesoscale and regional-scale atmospheric circulation. The model has been very successful in regional climate and seasonal prediction applications.
Inputs	Initial and lateral boundary conditions from NCEP GCM.
Outputs	Weather elements.
Lead time	Forecasts up to five days.
Model: PRECIS	
Characteristics	Downscaling tool that adds fine scale (high resolution) information. It generates high-resolution climate change information for as many regions of the world as possible.
Inputs	Initial and lateral boundary conditions from UK Met office.
Outputs	All the climate variables: rainfall, temperature, wind.
Lead time	Monthly, seasonal, annual, decadal (Daily and hourly averages can be selected if required).
Model: RegCM4.1	
Characteristics	Regional climate model, suitable to study the tale connections through the band version. The model is very successful in dynamical down scaling.
Inputs	Initial and lateral boundary data + SST.
Outputs	Surface variables, radiation variables and atmospheric variables.
Lead time	Depend on the data used for the boundary condition.
Model: Nile Forecast System (NFS) which included the ESP model the component of the forecast	

Characteristics	Near real-time distributed hydro-meteorological forecast system. This model produces possible monthly runoff traces, which are subsequently disaggregated to daily data.
Inputs	Rainfall and potential evapotranspiration.
Outputs	Monthly runoff traces.
Lead time	About 3 month.
Model: RIBASIM-NILE	
Characteristics	River basin simulation model (simulation of the water distribution). The model compares the total demand of a node with the satisfied demand, and then defines the shortage.
Inputs	Inflows at the different nodes (inflow data series or as rainfall data series).
Outputs	N/A
Lead time	N/A
Model: HAD-DSS	
Characteristics	Simulates the behaviour of Lake Nasser. The model processes the inflow data combined with the operation rules of the dam to provide output time series for release, energy production, reservoir level and storage at Lake Nasser as well as any spillage.
Inputs	Inflow to Lake Nasser.
Outputs	N/A
Lead time	Support real time operation; week/10day/month.
Limpopo CS	
Model: SARCOF	
Characteristics	The Southern African Regional Climate Outlook Forum (SARCOF) is a regional seasonal weather outlook prediction and application process adopted by the fourteen countries comprising the SADC Member States in conjunction with other partners
Inputs	Temperature (air, min, max, soil), precipitation, atmospheric pressure, wind direction and speed, evaporation and humidity.
Outputs	Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season.
Lead time	About 3 month.
Niger CS	
Model: ECMWF: ERA-Interim	
Characteristics	ERA-Interim (ERAI) is the latest global atmospheric reanalysis produced by ECMWF. The dynamical core of the atmospheric model is based on a spectral representation for the basic dynamical variables, a hybrid vertical coordinate, and a semi-Lagrangean semi-implicit time stepping scheme. It provides weather forecast products. (Already described in section 2.2.1)
Inputs	Variational analysis of the basic upper-air atmospheric fields (temperature, wind, humidity, ozone, surface pressure), followed by separate analyses of near surface parameters (2 m temperature and 2 m humidity), soil moisture and soil temperature, snow, and ocean waves.
Outputs	Daily precipitation, temperature, relative humidity, solar radiation.
Lead time	32 days
Model: CSIR CCAM	
Characteristics	The conformal-cubic atmospheric model (CCAM) as seasonal forecasting system is currently being run operationally at the Council for Scientific and Industrial Research (CSIR) in South Africa. It provides weather forecast products.
Inputs	N/A
Outputs	Daily precipitation, temperature, relative humidity, solar radiation.
Lead time	1 month
Model: PCR-GLOBWB	
Characteristics	Grid-based model (coded in PCRaster) of global terrestrial hydrology.
Inputs	Precipitation, actual evapotranspiration, snow and ice dynamics.
Outputs	Daily discharge and water balance.
Lead time	N/A
Model: SWIM	
Characteristics	Comprehensive GIS-based tool for hydrological and water quality modelling in mesoscale watersheds. Semi-distributed, process based, daily time step, Muskingum routing, curve number method.
Inputs	Daily precipitation, air temperature and relative humidity and solar radiation, GIS for topography, soils, land cover, Data for crop and dam management.

Outputs	Daily discharge and water balance, hydropower generation, flood propagation in the Inner Niger Delta.
Lead time	1 month
Model: OPIDIN	
Characteristics	Peak and flood propagation statistical prediction model. Based on water level time series from 1956-2007 in the Inner Niger Delta. Can be easily used by stakeholders to read prediction on site.
Inputs	Water level time series and current water level in five specific stations.
Outputs	Period and level for the annual peak water level and the interval of confidence for three stations. Correlated flooding map.
Lead time	1 to 2 months
Oum-er-rbia CS	
Model: Al Masifa	
Characteristics	Predicts the "rainfall state" (dry, normal, wet) using the relationship between SST anomalies and regional precipitation
Inputs	N/A
Outputs	Seasonal prediction bulletins
Lead time	3-4 months
Model: Al Moubarak	
Characteristics	Uses the statistical correlation between the precipitation and the global climate patterns.
Inputs	N/A
Outputs	Seasonal prediction bulletins
Lead time	3-4 months
Model: RIBASIM (already presented to Eastern Nile)	
Model: CROPSYST	
Characteristics	Used as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment.
Inputs	- Location (Latitude weather, rainfall, daily solar radiation, vapour pressure deficit values) - Soil characteristics (Caption exchange capacity, PH, runoff, soil texture, layer thickness, field capacity, permanent wilting point, bulk capacity) - Crop and management characteristics (Irrigation, nitrogen fertilisation, phonological events, Phenology, Morphology, Nitrogen, harvest index)
Outputs	- Crop development and growth, water and nitrogen balance, salinity, residue fate, soil erosion, pesticide fate;
Lead time	Daily time step
Model: CRIWAR	
Characteristics	Calculates crop water requirements in irrigated command areas. It is an agro-hydrological model consisting in two modules: an irrigation water requirement module that determines the daily water demand of the cropped area and can be used to review alternative cropping patterns and a strategy module that allows to determine an optimal irrigation strategy.
Inputs	- First module: meteorological data, cropping calendars, crop coefficients, irrigation volumes - Second module: daily water consumptions, groundwater fluctuations
Outputs	- First module: Crop water requirements, Tailored cropping patterns; - Second module: optimal irrigation scheduling (weekly and monthly).
Lead time	N/A

3.2.3. Drought response

In order to assess the status of drought response in each case study, the topics below are analysed, following the same structure used for European characterization:

1) main stakeholders responsible for drought management process;
2) brief description of the drought management process (interaction between stakeholders);

3) typology of drought measures applied in each country/basin (including drought adaptation and mitigation measures and the European Drought Impact report Inventory);
4) existence of Drought Management Plans.

The main stakeholders (entities/ authorities) responsible for the drought management process in each case study are presented in Table 7 and their corresponding interaction in Table 8. Although there are different types of institutions which provide essential information for drought management, the interaction between them is not guaranteed, and some gaps were identified for each case study. In this context, after the tables, which present the information related to the stakeholders and their interaction, some issues on African drought management/response process are summarised.

Table 7. Institutions and stakeholders involved in drought management process in DEWFORA Case Studies.

Case Study	Stakeholders responsible for drought management process
Eastern Nile	National Meteorological Services Agency (NMSA) - Ethiopia; Sudan Meteorological Authority (SMA) - Sudan; Higher Council for Civil Defence - Sudan; Ministry of Water Resources and Irrigation (MWRI) – Egypt; Nile Forecasting Centre (NFC) - Egypt; Egyptian Meteorological Authority (EMA) - Egypt.
Limpopo	Southern African Development Community; Limpopo Watercourse Commission; National Meteorological Services; Southern African Regional Climate Outlook Forum (SARCOF); Greater Horn of Africa Climate Outlook Forum (GHACOF); Climate Outlook Forum for West Africa (PRESAO: PRÉvisions Saisonnières en Afrique de l'Ouest).
Niger	Ministries of Water, Agriculture, Forestry, Livestock, Civil Protection, Interior and Decentralisation; National Meteorological Agency.
Oum-er-Rbia	Oum er-Rbia Hydraulic basin Agency, the ONEP; Ministry of Agriculture and Maritime fisheries: ORMVAs (Offices Régionaux de Mise en Valeur Agricole- Regional offices for agricultural development); Regional Directions of Agriculture; Water Users associations; HCEFLCD (Forestry administration), Insurance companies, Representatives of Ministries of interior, health and finance; National Direction of Meteorology (DMN).

Table 8. Interaction between institutions and stakeholders for drought management.

Case Study	Interaction between institutions and stakeholders
Eastern Nile	The Meteorological Agencies, such as NMSA, SMA and EMA, are responsible for providing forecasts of meteorological and hydrological droughts to the responsible ministries. The Sudan Meteorological Authority and Ministry of Irrigation and Water Resources provide advice to policy makers in all issues about climate and weather and provide data and information for public use, scientific research and farmers. The Sudan Meteorological Authority has field teams assigned to help farmers with seasonal crops and drought preparedness / response (is it not clear if they are ensuring that job presently). Farmers give feedback to the SMA providing reports on rain/drought seasons and on accuracy of forecast.
Limpopo	Limited information was provided.
Niger	Regarding the drought management process and interaction of institutions and stakeholders, there is an inter-ministerial committee lead by the Ministry of Interior and supported by the National Meteorological Agency and Early Warning System (SAP), which are in charge of managing droughts. These national institutions are supported by regional institutions for providing scientific information such as: ACMAD and AGRHYMET. (ACMAD is the Weather and Climate Centre with African continental competence. ACMAD's mission is the provision of weather and climate information and for the promotion of sustainable development of Africa, in the fields of agriculture, water resources, health, public safety and renewable energy. AGRHYMET is a specialized agency of the 'Permanent Inter-State Fight against Drought in the Sahel' (CILSS), composed of nine member states. It is a public multistate organisation with legal representation and financial autonomy.) Once a drought year is forecasted by national and regional institutions, this information is made available to the inter-ministerial committee. This information is put in more understandable materials for different target stakeholders by local radios and national TV. At this stage, the inter-ministerial committee starts preparation for preparedness activities.
Oum-er-Rbia	Regarding the drought management process and interaction of institutions and stakeholders, at the river basin level, drought management issues are under the supervision of Regional Drought Committees (RDC) headed by the Wali of the corresponding economic regions (that covers several provinces). The regional drought committee is responsible for all decisions pertaining to the national drought mitigation plan related measures and actions to be implemented in the region. This committee includes representatives of key ministries (ONEP, ORMVA, DRA, ABH) and elected members of the rural and urban collectivities of the region, in addition to active NGO's operating in the region. At the province level, the coordinating role and the composition of the Provincial Technical Committee are similar to those of the regional drought committee at the region level. At the local level, a number of Local Drought Committees / Specialized Drought Committees representing ministry line agencies and NGO's are responsible for detailed examination of the content of the proposed measures in order to match the needs of the local drought affected population, livestock and environment.

In addition to the collected information presented above, some limitations were identified regarding the interaction between stakeholders and the use of the available information:

- Most stakeholders at each level rarely share sectorial information among themselves and any information individually shared without consensus to each level creates competition for recognition and thus undermines timely interventions; delivery systems for disseminating data to users in a timely manner are not well developed, limiting their usefulness for decision support;

- There is no coordinating framework that brings together the different streams of information into a multi-sectorial early warning system that assesses hazards in, e.g., agriculture, health, nutrition, and natural resources management. There should be one major unified early warning system that assesses multi-sectorial hazards, including monitoring of drought risk, food insecurity, health epidemics, malaria outbreaks, livestock diseases, and market information;
- In the Oum-er-Rbia case study for example, each institution monitors a specific type of drought (meteorological, hydrological, agricultural or socio-economic) but there is no functional entity that coordinates and compiles all the drought information in a single product.

According to the experience of the case studies under study in DEWFORA project, it was possible to identify some of the mitigation and adaptation measures usually implemented and envisaged in African countries.

Drought adaptation measures

- Sensitization and organization of the population for the conservation of natural resources for training in simples practices for adaptation to climate change;
- Development of techniques of conservation and storage of water in particular to face the risks of dryness in the vulnerable areas (e.g. construction of small scale dams);
- Increase irrigation water use efficiency and agricultural productivity in old lands;
- Protection of waters against pollution of any origin (urban, industrial, agricultural waste);
- Provide technical packages for the farmers and local communities (such as best crop varieties (more resistant), land preparation, planting methods, technologies and fertilizer application);
- Livestock accumulation and changing herd/species composition;
- Creation of food stores;
- Integrated resources water management for taking account of the various users;
- Strengthening sub-regional cooperation in the field of transboundary resources water management;
- Promote the collection and management of hydro-climatic data;
- Use of meteorological information for improving agricultural production and contributing to food security;
- Establishment of an early warning system;

- Introduction of applied research products in agriculture and livestock-breeding;
- Drawing up of the farming calendar depending on crops, through the research support;
- Decentralized financial systems; setting up of micro-credit systems; regular supplying with subsidized animal-feed;
- Assessment of climate change impacts on the health and well-being of the population;
- Drawing up of plans for warning against extreme weather conditions with a view to preventing their effects on the population.

Drought mitigation measures

- Training of local communities and farmers on mitigation measures;
- Identify communities most affected by drought;
- Ensure food Security;
- Mobilizing social support and claims;
- Mitigate drought impacts through irrigation;
- Use of drought resistant crops;
- Community seed saving and construction of grain storage;
- Promotion of animal-feed and cereal banks;
- Providing water through emergency sources;
- Use of meteorological information for improving agricultural production and for contributing to food security.

In general, in African countries the link between drought monitoring and drought response should be improved in order to better prepare drought events and minimize their impacts. Regarding drought response in Africa, there are some early warning systems at country level. Zambia is an example of this. An Early Warning System has been established that has assisted the country to intervene and take necessary measures where drought has occurred. However, even though there has been regular collection of rainfall data and regular forecasting there has been little utilization of this information by most of decision makers because the information appears complex.

Another example of measures applied to improve drought response is the National Drought Management Authority (NDMA) in Kenya, which was created to provide leadership and coordination of drought risks and enhance the adaptation to climate change. NDMA is a statutory body established under the State Corporations Act (Cap 446) of the Laws of Kenya by Legal Notice Number 171 of November 24, 2011. It provides a platform for long-term planning and action, as well as a mechanism for solid coordination across Government and with all other stakeholders.

In terms of Drought Management Plans, despite the international efforts, the implementation of this tool is at a very early stage. One example is the Sahel drought management protocols such as PREGEC (Project de Gestion des Crises), but only in some drought prone areas the drought management plans have been developed and considered as part of national security and prevention plans (Vicente-Serrano et al., 2012).

4. New developments in drought monitoring and Early Warning Systems in African river basins

In the DEWFORA project many studies were made in order to improve the capabilities of African countries to drought response. In the following chapters the main improvements on drought monitoring and early warning systems for each case study are presented, namely the improvements on meteorological, hydrological and agricultural drought forecasting, climate change studies and drought vulnerability assessment. The information presented is based on the responses to the questionnaire made by UPorto (Faculty of Engineering), envisaging the characterization of the main improvements (developed under the scope of DEWFORA project) in processes of drought monitoring, forecasting and response in DEWFORA case studies – Annex B and on DEWFORA deliverables that have already been completed.

4.1. Drought monitoring

With regards to drought monitoring and drought indices it should be mentioned the development of a Pan-African Map Server that presents drought relevant information for entire African continent, such as specific indices that are also applied in the European context, and which is based on data processed and analysed at the JRC. Drought products shall include monthly updated SPI, and remote sensing observations on the state of the vegetation cover, i.e. anomaly of the fraction of Absorbed Photosynthetically Active Radiation (fAPAR), Normalized Difference Water Index (NDWI) (Horion et al.,2012).

A new approach was made based on the application of SPI to different rainfall datasets in order to assess its applicability in the study area. Historical and future meteorological drought occurrence over the Eastern Nile sub-catchments is assessed through calculating the Standardized Precipitation Index – SPI using the catchment rainfall from several sources. For historical rainfall, three datasets are used and results are compared in terms of drought frequency for a period starting in 1961 and ending in 1990 or beyond (except for the NFS dataset which starts in 1992). Future rainfall is taken from an ensemble of 6 RCM simulations for the period 2021-2050. The baseline rainfall series from the ensemble members (1961-1990) are first compared to observed rainfall and SPI before the impact of climate change on the frequency of drought is assessed.

The SPI has been calculated for catchment rainfall over the Blue Nile and Atbara sub-basins for the current climate from three different sources. These are the Climatic Research Unit (CRU) rainfall dataset, the ECMWF Rainfall Reanalysis dataset (ERA40), and the gauge-satellite merged rainfall dataset produced by the Nile Forecast System (hereafter referred as the NFS dataset). For the future climate, dynamically downscaled rainfall from an ensemble of 6 simulations is used. These were produced by the PRECIS regional climate model (RCM).

The main conclusions obtained through this study show that ERA40 rainfall is overestimated for the Eastern Nile region compared to CRU and NFS rainfall datasets for the early part of the record, distorting the rainfall distributions, and to a lesser extent, the SPI distributions. CRU rainfall is higher than NFS for the region during the peak rainfall, and thus leads to higher flood probabilities but similar drought probabilities. When run using ERA40 boundary condition (which does not include precipitation), PRECIS overestimates rainfall over the whole year, resulting in different seasonal rainfall distributions compared to ERA40 rainfall. This has its effect on the SPI as some dry years may be seen as wet and vice versa. Such biases need to be corrected, but their effect is somewhat reduced in calculating SPI because it involves normalization of rainfall distributions.

The current set of climate simulations indicate a general increase in rainfall over the region but this does not exclude the increase of drought probability for some lead times especially longer ones and on the scale of the hydrologic year. The uncertainty bandwidth (defined by the range across the different simulations) increases near the ends of the SPI probability distributions but not for all lead times.

The SPI proved to be a useful way to characterize meteorological drought across different catchments and at different time scales. Because it normalizes the rainfall distribution, it is less sensitive to systematic biases in the data (i.e. systematic overestimation or underestimation – shifts in the mean).

4.2. Drought forecasting methods

- Meteorological forecasting

In this theme, in Eastern Nile, Limpopo, Niger and Oum-er-Rbia case studies, an integrated monitoring and forecasting system was developed based on the Standardized Precipitation Index (SPI), on multiple globally available precipitation products (ERA Interim and CAMSOPI), which are available in near real time, and on the ECMWF (European Centre for Medium-Range Weather Forecasts) Seasonal Forecasting System 4 (S4). In the specific case of Oum-er-rbia, the implementation and skill assessment of medium range to seasonal forecasts was performed, and in the Eastern Nile case study the relation between El Niño – Southern Oscillation (ENSO) and drought and flood events and its contribution for seasonal forecasting was studied.

– Hydrological forecasting

In what concerns hydrological drought forecasting, in Eastern Nile case study a set of three indices has been applied to observed as well as simulated and forecasted flows using the NFS hydrological and forecasting components respectively. This helped assessing the applicability of these indices and evaluating the NFS in predicting drought. In the Limpopo case study a downscaled and adapted version of "PCR-GLOBWB-Africa" model was developed; and two different approaches were studied for hydrological drought forecasting: a statistical seasonal forecast and a dynamic multi ensemble seasonal forecast. In the Niger case study, a continuous improvement and development of OPIDIN tool was performed and the eco-hydrological model SWIM (Soil and Water Integrated Model) was selected and tailored to reproduce past drought events with monthly bias corrected reanalysis climate datasets.

– Agricultural forecasting

For the improvement of agricultural drought forecasting, on Limpopo and Oum-er-Rbia case studies statistical methods were applied in order to develop prediction models for seasonal crop yields.

4.3. Effects of climate change

Concerning the study of the effects of climate change on drought risk using climate projections and vulnerability maps, the impact of climate change on the Eastern Nile basins was studied in terms of: rainfall, evapotranspiration, temperature, and flow at the outlet location of Blue Nile and Atbara. In this study six ensembles are selected from 17 runs of GCM model (HadCM3) to be downscaled by Regional Climate Model (PRECIS) during the period 1961-1990, the base period, and the 2021-2050 future period.

Regarding the influence of climate change on the Eastern Nile basins, it was verified an expected increase of rainfall and flow variability, and in what concerns potential evapotranspiration, a slight increase is expected. This will reduce crop yields unless rainfalls compensate the loss due to the increasing heat.

The current set of climate simulations indicate a general increase in rainfall over the region but this does not exclude the increase of drought probability for some lead times especially longer ones and on the scale of the hydrologic year. The uncertainty bandwidth (defined by the range across the different simulations) increases near the ends of the SPI probability distributions but not for all lead times.

4.4. Drought vulnerability

On this issue, a drought vulnerability map at the rural community level was developed for Oum-er-Rbia case study. Similarly an assessment of vulnerability at the county level in Kenya was developed. These are based on a composite drought vulnerability index integrating 4 different components: (i) the renewable natural capacity, (ii) the economic capacity, (iii) human and civic resources, and (iv) infrastructure and technology. This map represents the first drought vulnerability map at the community/county level ever realized at the basin level or even the country level and can be .co

The drought vulnerability assessment and mapping at the community level represents a tool for decision makers allowing the development of efficient mitigation actions, tailored to the needs and specificities of each community.

5. Comparative review of European and African perspectives on drought monitoring, forecasting and response

The comparative review of the systems presented (European and African) allows the definition of guidelines for the improvement of drought preparedness methods, taking into account the main needs of each one and differences between both due to regional concerns.

5.1. Main needs for drought capabilities in African Case Studies

Taking into account the African case studies and regarding their capabilities in what concerns drought preparedness, the main gaps identified were:

- Collection data issues
  - Meteorological and hydrological data networks are inadequate in terms of the density of stations for all major climate and water supply parameters. Data quality is also problematic because of missing data or a short length of record.
  - The use of atmospheric forcing, socioeconomic parameters related to assessment of drought impacts, soil information, satellite data (including AVHRR, MODIS, GRACE, SRTM, AATSR) and routing networks is limited.
  - Data sharing between government agencies and research institutions is inadequate.
  - Delivery systems for disseminating data to users in a timely manner are not well developed, limiting their usefulness for decision support.
  - High costs limits application of data in drought monitoring, preparedness, mitigation and response. Rainfall, temperature data and derived parameters are costly, as the national meteorology agencies, which are public institutions, charge high fees even if the data is required by education and research institutions.
  - The current approach to financing data collection is not appropriate. There is limited collaboration with agencies such as NASA, NOAA, United States Geological Survey (USGS), WMO, United Nations (UN), etc.

- Technical issues

- The limited skills of scientists, technicians and support staff are a reality in many cases. At the same time, the capacity building efforts are inadequate.
- The forecasting and early warning systems available in Africa are not adequately maintained; recalibration and troubleshooting are inadequate.
- The limited involvement of scientist/specialists in Africa in designing and developing early warning and forecasting systems means that local knowledge is not incorporated in "state of the art" decision support tools, which results in unreliable products at regional and local levels.
- Funding for research programmes especially on water resources assessment, hydrological modeling, water accounting and data compatibility is inadequate.
- Limited climate based monitoring, scientific analysis and research.
- Capacity is required at all levels (researchers, meteorologists, technology transfer, farmers, policy makers, communities, etc) for effective interpretation and usage of forecasting and early warning products.

On the other hand, the organizational structures in Africa are characterized by the general lack of specific departments with a mandate to deal with drought related issues and a lack of structures for managing drought at the local level. Additionally, responsibilities are divided among too many institutions with very little capacity. There is a lack of coordination and integration amongst institutions involved in drought management, resulting in duplication of effort and conflict; the involvement of the private sector is very weak, and there is inadequate infrastructure including drought forecasting systems, advanced models and software and a lack of equipment and technology to generate usable/credibility of information. That adds to the fact that there is/are: no clear drought management policies and drought mitigation plans; poor support for uptake of science at policy level, and; inadequate financial resources, lack of technical capacity, insufficient human resources and inadequate training.

5.2. Main similarities and differences between European and African perspectives

Comparing the European and African perspectives, in what concerns the drought management process, it is possible to verify that there are various differences, namely regarding policy and technical developments. The European perspective seems to be more updated and focused on preparedness drought at national, regional, and river basin level.

At EU level, there is a Directive (WFD), which has the main objective is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater, in order to mitigate the effects of both floods and droughts, among others. Regarding drought events, the Communication on Drought & Water Scarcity to the European Commission (COM(2007) 414), presented in 2007, promote the development of Drought Management Plans, in order to improve the drought risk management. It is also important to highlight that efforts are being developed in order to prepare and implement an EU Droughts Directive, similarly to the Floods Directive, that is already in force. Regarding the technical issues, the implementation and continuous improvement of the European Drought Observatory through Joint Research Centre allows the permanent analysis of drought-relevant indicators, provide up-to-date information and give an overview of the situation in case of imminent droughts. The development of new capabilities and the improvement of the current tools used for drought risk management, (e.g. the drought early warning systems) will allow achieving the goal of improving drought preparedness and reducing drought impacts. In a general view, increasingly, the European countries seem to be more involved in drought issues, working to coordinate and facilitate the development and application of drought risk management tools.

In the African perspective, there are no clear drought management policies and the efforts for the development of drought mitigation plans are at a very early stage, mainly because drought management is done through reactive rather than proactive actions. At the African level, there is no common policy on drought management. The observed actions are being implemented individually by each country. Regarding technical and human resources issues, some negative points in were identified in comparison between the African and European position: lack of technical capacity, insufficient human resources and inadequate training and financial resources. On data collection it was identified that data networks are inadequate in terms of the density of stations, quality, limited availability and high cost of historical data. At organization level there is a lack of coordination and interaction amongst institutions, the responsibilities are divided among too many institutions, and there is a lack of structures for managing drought at the local level, and of equipment and technology to generate reliable information: forecasting systems, models and software.

According to the analysis above it was verified that the European drought management process is more updated and the main gaps are identified in a more advanced stage of the process, when compared with African situation. In other words, guidelines, strategies, tools, equipment and knowledge exist but should be implement or, in many cases, only improved. In the African case, the drought management process seems to be dispersed and there are as yet no guidelines/laws that are standardized across all countries in a given climatological region, let alone in the continent as whole.

6. Summary and conclusions

Through the European experience and the identified needs/gaps in drought management process of African countries, recommendations are proposed in order to improve their strategy at technical level: (i) it is important to overcome the difficulties associated with data collection and processing, and improve drought monitoring and forecasting tools; (ii) equipment and technology to generate usable/credible information are necessary; (iii) more human resources (scientists, technicians and support staff) and appropriate infrastructure/equipment are required; (iv) the involvement of scientist/specialists in Africa to design and develop early warning and forecasting systems (with advanced models and software) and to develop the drought monitoring, scientific analysis and research regarding climate are expected to significantly improve the drought monitoring, forecasting and response situation in Africa. Nonetheless, the integration of scientific and local knowledge is indispensable; and funding for research programs especially in water resources assessment could be advantageous.

On the organizational component, several improvements are proposed: (i) the creation of new organizations operating at the overall basin level, responsible for water resources management and protection, that could improve the situation regarding drought monitoring and management at the basin/ local level; (ii) the coordination and integration amongst institutions involved in drought management; (iii) the development of drought management policies and drought mitigation plans; (iv) training and public awareness campaigns, the participation of stakeholders and water uses and the effective transfer of information to policy and decision-makers are important to improve drought mitigation and adaptation (more reliable, specific and understandable information).

In both cases, but especially in African countries, it is important to improve drought mitigation and adaptation, having more attention on: training and public awareness campaigns mainly in situations where the country is approaching a drought season; participation of stakeholders and water users; spatial resolution of early warning systems and updating intervals e.g. seasonal climate outlooks and monthly updates; integrating scientific and local knowledge based drought forecasting and monitoring systems; effective transfer of information to policy- and decision-makers; performance evaluation and improving capacity of the institutions at regional, national and local levels; and improve link between relief efforts and development programmes.

Regarding the impact assessment methodologies, a critical part of drought monitoring and early warning systems, these should be standardized or widely available, improving the impact estimates and the creation of regionally appropriate mitigation and response programmes. Nonetheless, the declaration of drought situations and early warning systems, the adoption of adequate indicators, the monitoring of drought effects and the planning of measures to be adopted in drought situations should be coordinated at basin level, although the existing specificities at national and local level should also be taken into account for the effective implementation of both drought monitoring and response.

7. References

Acácio, V., Andreu, J., Assimacopoulos, D., Bifulco, C., di Carli, A., Dias, S., Kampragou, E., Haro Monteagudo, D., Rego, F., Seidl, I., Vasiliou, E., Wolters, W. (2013). Review of current drought monitoring systems and identification of (further) monitoring requirements. Drought R&SPI.

DEWFORA (2011). G*ap analysis report on drought monitoring and forecasting systems in Africa*, Work package 2, Deliverable 2.4, Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa.

DEWFORA (2011) Gap analysis report on drought mitigation and adaptation practices and organizational structures for drought management in Africa, Work package 2, Deliverable 2.5, Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa.

DEWFORA (2012). Performance Assessment on Droughts Evaluation - Case Study Initial Situation, Task 6.6, Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa.

DEWFORA (2013). Framework for drought warning and mitigation from national to local scale, Work package 5, Deliverable 5.3, Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa.

Dutra, E., Giuseppe, F., Wetterhall, F. & Pappenberger, F. (2012) Seasonal forecasts of drought indices in African basins, Hydrology and Earth System Sciences Discussions, 9, p. 11093-11129.

EC. (2007). Addressing the challenge of water scarcity and droughts in the European Union. COM (2007) 414 final - Communication from the commision to the European Parliament and the Council.

EC. (2007). Water Scarcity and Droughts. European Parliament - Policy Department Economic and Scientific Policy.

EC. (2012). Final Report - Gap Analysis of the Water Scarcity and Droughts Policy in the EU. European Commission.

EEA. (2005). The European Environment—State and outlook 2005. European Environment Agency.

EEA. (2009). Water Scarcity and Drought: towards a European Water Scarcity and Drought Network (WSDN). European Environment Agency.

Estrela, T. (2006). La gestión de las sequías en España. Ingeniería y Territorio. Catástrofes naturales 74, 52-57.

Estrela, T., & Vargas, E. (2012). Drought Management Plans in the European Union. The Case of Spain. Water Resour Manage.

Horion, S., Carrão, H., Singleton, A., Barbosa, P., & Vogt, J. (2012) JRC experience on the development of drought Information Systems – Europe, Africa and Latin America, JRC Scientific and Technical Reports.

Mishra, A. K. & Singh, V. P. (2010) A review of drought concepts, Journal of Hydrology, p. 202-216.

UN. (2007) Africa Review Report on Drought and Desertification, Fifth Meeting of the Africa Committee on Sustainable Development, United Nations, Economic and Social Council, Economic Commission for Africa.

Stahl, K., Blauhut, V., Kohn, I., Acácio, V., Assimacopoulos, D., Bifulco, C., Stefano, L., Dias, S., Eilertz, D., Frielingsdorf, B., Hegdahl, T., J., Kampragou, E., Kourentzis, V., Melsen, L., A.J. van Lanen, H., F. van Loon, A., Massarutto, A., Musolino, D., Paoli, L., Senn, L., Stagge, J. H., Tallaksen, L. M., & Urquijo, J. (2012) A European Drought Impact Report Inventory (EDII): Design and Test for Selected Recent Droughts in Europe, Technical Report no. 3, Drought R&SPI.

Vicente-Serrano, S. M., Beguería, S., Gimeno, L., Eklundh, L., Giuliani, G., Weston, D., Kenawy, A., López-Moreno J. I., Nieto, R., Ayenew, T., Konte, D., Ardö, J. & Pegram, G. G. S. (2012). Challenges for drought mitigation in Africa: the potential use of geospatial data and drought information systems. Applied Geography, 34, 471-486

ANNEX A

"Performance Assessment on Drought Monitoring, Forecasting and Response in Europe" Questionnaire

Performance Assessment on Drought Monitoring, Forecasting and Response in Europe

This questionnaire is made under the scope of a FP7 RTD European Project named DEWFORA.

The main aim of DEWFORA is to reduce vulnerability and strengthen preparedness to droughts in Africa by advancing drought forecasting, early warning and mitigation practices.

DEWFORA will provide guidance on how and where drought preparedness and adaptation should be targeted to contribute to increased resilience and improved effectiveness of drought mitigation measures. For that, the experiences in Europe will be used to define the state-of-the-art for drought monitoring, forecasting and response.

Therefore, regarding a more detailed characterization of the situation in the European countries, the aim of this questionnaire is:

1. To collect information on the degree of awareness concerning the issue of drought impacts on water resources.
2. To characterize main drought monitoring, assessment and forecasting tools.
3. To identify the main stages of the drought management process.
4. To compile information on potential adaptation and mitigation measures and strategies as well as on implementation experiences.
5. To understand what are the main Climate Change concerns regarding potential impacts on water resources.

The structure of this Questionnaire is the following:

Topic 1: Identification of Your Institution

Topic 2: Drought Monitoring, Assessment and Forecasting Tools

Topic 3: Drought Management Process

Topic 4: Drought Adaptation and Mitigation Measures and Stretegies

Topic 5: Climate Change Concerns

Note: If you do not know or have information on some topics, or if the scope of your Institution is not related to some of these subjects, we will appreciate if you could indicate instead where and/or who may provide that information.

Please use the information box to answer the last question for that (Page 5, Question 20), indicating the number of the question stake.

Identification of your Institution

1 Please indicate the name of your Institution

1.2 Please indicate the name of the contact person

1.3 Please indicate the European Country(ies) in which your institution is working

1.4 Please indicate the scope of your institution, regarding Drought Management and Evaluation

- Monitoring
- Forecasting
- Response
- Other

Drought Monitoring, Assessment and Forecasting Tools

2 Which indices/indicators are used for drought monitoring in your region/jurisdiction area?

3 How feasible can the drought monitoring be considered? (Please characterize from 1 – Minimum to 10 – Maximum)

4 What type of forecasting models are used?

5 How accurate are the forecasting results of the existing tools? (Please characterize from 1 – Minimum to 5 – Maximum)

- Meteorological
- Hydrological
- Agricultural

6 How fast and efficient is the current flow of information related to drought assessment and management? (Please characterize from 1 – Minimum to 5 – Maximum)

- Slow/fast
- Inefficient/Efficient

7 Which sectors are more vulnerable to drought in your region/jurisdiction area?

- Livestock
- Drinking Water/Urban Water use
- Forests
- Economic and Social Life
- Tourism
- Hydropower production
- Agriculture
- Endemic Fauna and Flora Species
- Fishing, Hunting, and Recreation
- Other

Drought Management Process

8 What are the main stakeholders (authorities, agents, entities) responsible for drought management process, in your region/jurisdiction area?

> 8.1 Can you describe shortly the drought management process and the interaction between the listed stakeholders?
>
> 8.2 What do you think, is the feedback from stakeholders, in terms of effectiveness of current drought response process? (Please characterize from 1 – not effective to 10 – effective)
>
> 8.3 What do you think, is the feedback from population in terms of effectiveness of current drought response process? (Please characterize from 1 – not effective to 10 – effective)

9 Is there any Drought Management Plan already developed/implemented for your region/jurisdiction area? (Yes, No, Don't know)

9.1 If yes, where is it possible to get it?

10 Is there also any drought risk/vulnerability mapping? (Yes, No, Don't know)

10.1 If yes, where is it possible to get it?

11 Are there any drought early warning systems / monitoring systems?

- Early Warning Systems
- Drought monitoring systems
- Don't Know
- Other

12 When was the last drought situation in your region/jurisdiction area?

Drought Adaptation and Mitigation Measures and Strategies

13 Is there any record of drought impacts, mitigation and/or adaptation measures adopted for past drought situations in your regional area of study?

- Drought Impacts
- Drought Mitigation Measures
- Drought Adaptation Measures
- None of them

13.1 If yes, please indicate where is it possible to get it, and what is(are) the institution(s) responsible?

14 The following table lists a number of potential adaptation measures. Please indicate which of these you consider important in your region/jurisdiction area, and characterize them according the following numerical classification: (1- Implemented; 2 – Planned; 3 – Necessary (but not planned yet); 4 – Not relevant/necessary; 5 – Not applicable/Don't Know)

- Legal regulations to improve water savings
- Public awareness campaigns
- Wastewater reuse for specific purposes
- Contingency planning and definition of emergency actions for drought impacts mitigation

- Development of Early warning system
- Hydrological forecasting and drought monitoring
- Application of optimization, risk, and decision support models
- Reinforcing the use of rainfall harvesting, water cisterns, fog collection, etc.
- Groundwater recharge
- Demand delivery scheduling in pressurized systems
- Selection of crop varieties according to their tolerance to water stress conditions and dry conditions
- Tillage and land-forming practices (soil management)
- Improving surface irrigation measures
- Adopting water prices that induce farmers to save water and to irrigate during night
- Farmers involvement in decisions to change delivery schedules dictated by limited supply
- Terracing (maximization of soil infiltration)
- Use of small dams (farm ponds), also to increase aquifer recharge

14.1 Please indicate additional measures if necessary.

15 The following table lists a number of potential mitigation measures. As in topic 14, please indicate which you consider important for your region/jurisdiction area, and characterize them according the following numerical classification: (1- Implemented; 2 – Planned; 3 – Necessary (but not planned yet); 4 – Not relevant/necessary; 5 – Not applicable/Don't Know)

- Analysis of available resources and possible optimization of water uses
- Definition of strategic water reserves for priority uses
- Realization of public awareness campaigns
- Constitution of a technical drought committee to follow up drought evolution
- Control of drought measures' implementation
- Water conservation recommendations for farmers
- Control of water allocation in irrigation areas
- Activation of emergency plans in water supply systems
- Use of non-conventional water resources
- Adaptation of reservoirs exploitation rules
- Increase of water quantity and quality monitoring

- Reinforcement of water discharges control and increase of penalties for irregular discharges
- Water use restrictions in irrigation areas
- Activation of water systems interconnections (If existent)
- Reduction of pressure head during night periods
- Intensification of water resources transfer within the river basin (If existent)
- Reallocation of water resources
- Obligatory water use restrictions
- Restriction in flows to satisfy environmental needs
- Increase of penalties for irregular discharges
- Restrictions for some crops cultivation
- Restriction of water use for certain purposes (Streets cleaning, car wash, etc.)
- Water tanks supply
- Temporary change of water tariffs for urban supply
- Use of the minimum or strategic water reserves to cover environmental needs and household supply's

15.1 Please indicate additional measures if necessary.

Climate Change Concerns

16 In your opinion, is there an increase of drought vulnerability (Due to Climate Change or not)? (Yes, No, Don’t know)

17 Regarding the possible scenarios of climate change, how sensitive can be considered the water resources in your region/jurisdiction area? Please give a judgement for different areas as relevant in your country (1 – Very sensitive; 2 – Sensitive; 3 – Slightly sensitive; 4 – Not sensitive; 5 – Not applicable/ Don’t know)

- Coastal areas
- Mountainous areas
- Lowland areas
- Urban areas
- Agricultural areas
- Industrial areas

- Other economically critical areas (e.g. airports, harbours)

18 Which of the following means of communication do you use more to share the information about droughts and climate change? Please classify 1 as most used to 5 as less used.

- Community information meetings
- Environmental groups
- Mass Media (Newspaper or magazines, radio or television)
- The Internet
- Technical or scientific publications

19 Are you aware of any research projects, related to Drought and/or Climate Change, that were made for your region/jurisdiction area?

20 Other considerations

ANNEX B

"Performance Assessment on Droughts Capabilities" Questionnaire 1

Case Study Initial Situation

Performance Assessment on Droughts Capabilities – Q1

Please complete the questionnaire for Performance assessement on the actual drought capabilities on your Case Study. It was divided in 3 main worksheets according to the type of assessment in stake - "Drought monitoring and assessment", "Drought Forecasting" and "Drought response". From the analysis of the respective Case Study Inception Report, some information related to each topic was collected, whenever available. If the information provided is incorrect or incomplete, please correct it.

Performance Assessment on Drought Monitoring

1 Drought Monitoring Indicators

1.1 Is there any regular drought monitoring evaluation?

1.2 If yes, which indices/indicators are used?

1.3 Which base data is needed?

1.4 Is data easily available?

1.5 How feasible is drought monitoring (characterize from 1 - unfeasible to 10 - accurate)?

2. Impact of Climate Change

2.1 Extension of record data

2.1.1 Precipitation Data

2.1.2 Temperature Data

2.2 Are any previous climate change studies available?

2.3 Is there an increase of drought vulnerability with Climate Change?

2.4 What regions are more vulnerable?

3 Risk/Vulnerability Mapping

3.1 Is there any drought risk mapping?

3.2 If yes, how useful are the risk maps?

3.3 Is map resolution useful?

Performance Assessment on Drought Forecasting

4 Meteorological Drought Forecasting

4.1 What models are used? (Short description)

4.2 What are the main characteristics of the models?

4.3 What are the inputs of data needed?

4.4 What are the outputs?

4.5 How much time in advance (Lead time) is it possible to forecast?

4.6 How accurate is the forecasting of the existing tools (characterize from 1 - unfeasible to 10 - accurate)?

5 Hydrological Drought Forecasting

5.1 What models are used? (Short description)

5.2 What are the main characteristics of the models?

5.3 What are the inputs data needed?

5.4 What are the outputs?

5.5 How much time in advance (Lead time) it is possible to forecast?

5.6 How accurate is the forecasting of the existing tools (characterize from 1 - unfeasible to 10 - accurate)?

6 Agricultural Drought Forecasting

6.1 What models are used? (Short description)

6.2 What are the main characteristics of the models?

6.3 What are the inputs data needed?

6.4 What are the outputs?

6.5 How much time in advance (Lead time) it is possible to forecast?

6.6 How accurate is the forecasting of the existing tools (characterize from 1 - unfeasible to 10 - accurate)?

Performance Assessment on Drought Response

7 Response to Drought (management)

7.1 Is there any record of drought impacts and/or drought mitigation measures adopted for past drought situations?

7.2 Estimation of drought impacts on:

7.2.1 Population (inhab affected)

7.2.2 Economy (costs, losses)

7.2.3 Main problems occurred

7.3 What are the main stakeholders (entities/ authorities) responsible for drought management process?

7.4 Please, describe shortly the drought management process and interaction of stakeholders.

7.5 What is the feedback from stakeholders, in terms of effectiveness of current drought response process (characterize it from 1 - not effective, to 10 - effective)?

7.6 What is the feedback from population (if existent) in terms of effectiveness of current drought response process (characterize it from 1 - not effective, to 10 - effective)?

7.7 How fast and efficient is the current flow of information related to drought assessment and management (characterize it from 1 - slow and inefficient, to 10 - fast and efficient)?

8 Preparedness and Adaptation to droughts and Climate Change

8.1 What measures can be recommended to improve preparedness in the region?

8.2 How likely will they be applied?

8.3 Is there any estimation of the costs involved?

9 Enhanced DEWS and Mitigation

9.1 What are the main expectations in relation to Drought Early Warning Systems (DEWS) and Mitigation improvements?

9.2 What is the time necessary for implementation?

9.3 Is financial support available?

9.4 Is the improved framework applicable?

Other information

ANNEX C

"Performance Assessment on Droughts Capabilities" Questionnaire 2

Case Study Improvements

Performance Assessment on Droughts Capabilities – Q2

Performance Assessment on Drought Monitoring

1. Drought monitoring indicator
    a) Which improvements in drought monitoring evaluation were developed under the scope of DEWFORA project?
    b) Is there any additional index/indicator being used (compared to your response of *Questionnaire 1*)?
2. Impact of climate change
    a) Is there any additional information regarding the impact of climate change, according to DEWFORA developments?
    b) What regions are more vulnerable?
3. Risk/Vulnerability mapping
    a) Is there any additional risk mapping developed under the scope of DEWFORA?
    b) If yes, how useful are they?
    c) What regions are more vulnerable?

Performance Assessment on Drought Forecasting

4. Meteorological drought forecasting
    a) What are the main improvements regarding meteorological drought forecasting, attending to the characteristics detailed on *Questionnaire 1*?
    b) Are there some additional improvements that should be recommended on meteorological drought forecasting?
5. Hydrological drought forecasting
    a) What are the main improvements regarding the hydrological drought forecasting, attending to the characteristics detailed on *Questionnaire 1*?
    b) Are there some additional improvements that should be recommended on hydrological drought forecasting?
6. Agricultural drought forecasting
    a) What are the main improvements regarding the agricultural drought forecasting, attending to the characteristics detailed on *Questionnaire 1*?
    b) Are there some additional improvements that should be recommended on agricultural drought forecasting?

Other comments

a) Besides the above detailed topics, how do you describe DEWFORA's contribution to the improvement of Drought capabilities in your region?
b) What additional improvements can you suggest for the future?