



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

DEWFORA

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**Framework for drought warning and mitigation from national to
local scale**

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SUMMARY

The main objective of this document is to provide a guideline for a framework to downscale and package drought forecasts and produce early warning information suitable for application in defining implementable drought mitigation actions. The framework considers scientific advances in monitoring and forecasting at global, national and local levels. It also includes mechanisms to improve flow of this information to the local level from national to local scale to meet user preferences and provide actionable tasks/responses.

The framework for drought forecasting, early warning and mitigation in Africa proposed here will assist in establishing policy priorities based on scientific evidence that also strengthens existing institutions. Overall, a science-based approach is a useful guideline, but it faces a number of challenges some of which are explored in this document through evidence drawn from selected river basins in Africa as case studies namely; the Oum-er-Rbia River Basin, (Morocco), Eastern Nile Basin (Burundi, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda), Limpopo Basin (Botswana, Mozambique, South Africa and Zimbabwe) and Niger Basin (Algeria, Benin, Burkina-Faso, Guinea, Ivory Coast, Mali, Niger and Nigeria). Lessons are also drawn from Global systems, networks/ institutions (**See Annex A**).

Drought Identification and monitoring:

The main diagnostic indicators being applied to **detect** if a drought threat or hazard exists in Africa (Deliverable 2.1 (D2.1)) can be summarised as follows:

Standardised Precipitation Index (SPI), Palmer Drought Severity Index (PDSI); deviation analysis, decile rainfall, surface water supply index (SWSI); drought hazard and drought vulnerability assessment and mapping, vegetation condition index (VCI), water satisfaction index (WSI), Normalised Difference Vegetation Index (NDVI), drought operating rules and storage forecast trajectories, flow deviation, agricultural drought threshold, veld/forest production and insect production.



A growing number of datasets is becoming available which will be applied to improve the performance of drought monitoring systems. WP4 identified the following data:

- a) Countries - Global Administrative Areas database version 2.0 (GADM, <http://www.gadm.org/>) and the CIA World Data Bank II (<http://www.evl.uic.edu/pape/data/WDB/>).
- b) DEM produced from the Hydro1k Africa (USGS EROS Data Center 2006) and up-scaled to the model resolution of 0.05°
- c) Catchment boundaries and rivers - HydroSHEDS data set (<http://hydrosheds.cr.usgs.gov/>).
- d) the European Centre for Medium/Range Weather Forecasts (ECMWF) ERA-Interim (ERA-I) reanalysis and long-range weather forecasts
- e) the Council for Scientific and Industrial Research (CSIR) in South Africa conformal-cubic atmospheric model (CCAM) seasonal forecasting system

Drought Forecasting:

Seasonal forecasting provides a statistical summary of the weather events occurring in a given time period. The principal aim of seasonal forecasting is to predict the range of values which is most likely to occur during the next season. National meteorological agencies/departments (MET) provide weather forecasts as well as seasonal climate outlooks. Regional agencies also provide seasonal climate outlooks.

The ECMWF maintains two currently operational ensemble forecasting systems through its Variable resolution Ensemble Prediction System (VarEPS): (i) weather forecasts out to 32 days and (ii) seasonal forecasting produces forecasts out to 7 months. The forecasts are available at the ECMWF data finder in the GRIB format. The CSIR's CCAM is configured to generate a 28-year set of hindcasts as a result of forcing the CCAM with predicted, as opposed to persisted, SST anomalies. The operational forecasts and verification statistics are presented on the website of the South African Risk and Vulnerability Atlas (<http://rava.qsens.net/>). CAMSOP1 is a merged dataset produced by the NOAA Climate Prediction Centre (CPC). Local knowledge drought forecasting (LKDF) systems apply local knowledge to detect the onset of drought and the progression of the season.



Two hydrological models were tested on the Limpopo and Niger case study basins namely PC Raster Global Water Balance Model (PCR-GLOBWB) and the Soil and Water Integrated Model (SWIM).

For seasonal forecasts, forecasting precision decreases when the spatial focus is narrowed from global, to regional, to national, to local levels. There are also challenges in simplifying, downscaling and packaging information as warnings to address user preferences. For this reason, while seasonal forecasting tools utilizing atmospheric science may provide more useful information for regional droughts their applicability for at catchment scale, the main unit for water management is limited because they are not accurate enough for the requirements at this of scale. At catchment and local scales, local knowledge systems seem to perform better however more studies are required on these systems to create confidence in the scientific community.

Drought Early Warning:

Drought early systems based on local knowledge identified in D2.3 provide information on on-set of drought with varied lead times and overall period of seasonal outlook. Evidence of consistent issuing of climate based drought warnings and use of warnings is poor because of lack of documentation and this has limited the scientific advancement especially for knowledge systems. Stochastically generated forecast trajectories (flow and storage), historical statistics (rainfall, flow and storage) and cyclical behaviour (rainfall and flow) for drought early warning are the preferred options by water managers in Africa as they offer improved confidence through learning from historical patterns. There is an appreciation that future patterns may be different hence the need for new methods that incorporate climate based seasonal forecasts (D2.3).

Drought Response:

Drought response consists on actions that are activated whenever a warning threshold is overcome. Drought prevention concerns those measures aimed at preventing drought causing damage. Drought preparedness concerns those measures which enable societies to respond rapidly to drought. The most common drought response actions are food aid, drought relief programs, growing of drought tolerate crops, saving livestock, improved water use efficiency and installation of boreholes, wells and small dams (D2.2). Communities in Africa are engaged in activities to be able to survive future droughts and climate change, depending on duration and magnitude of deficit. This is being done through changes in processes, practices, and structures to moderate potential impacts of future drought. The most common actions being water harvesting, construction of water infrastructure,



traditional/cultural practices and technologies, water conservation, crop monitoring and crop diversification (D2.2).

Drought and Climate Change

The impact of climate change on frequency of occurrence and severity of droughts in Africa was analyzed using a variable-resolution coupled global climate model (CGCM) model, the conformal-cubic atmospheric model (CCAM). It was applied for both seasonal forecasting and the projection of future climate change. The Coordinated Regional Downscaling Experiment (CORDEX) ensemble of high-resolution projections of future climate change over Africa, uses different regional climate models, downscaling the output of the CGCM projections with simulations at about 50 km resolution. However the spatial resolution of CGCMs is inadequate for studying regional impacts of future climate change. Statistical downscaling requires long time-series of observed records of sufficient quality, for the empirical relationships to be established a severe limitation for most of Africa. Reliability of climate change projections can only be verified after several decades but successful replication of hind-cast trends can also increase confidence in forecasts

Drought Monitoring

Monitoring systems in African countries are inadequate considering the variability of precipitation and flow, sizes of catchments/aquifers and variability of geophysical conditions. In addition, historical data is not readily available to users. There is a decline on the meteorological stations due to high maintenance costs. 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. Locally collected data is also useful for regional, continental and global forecasting and early warning systems, but data sharing is inadequate between government agencies and research institutions. High costs limits application of data in drought monitoring, preparedness, mitigation and response. The current approach to financing data collection is not appropriate. There is limited collaboration with agencies such as NASA, NOAA, USGS, WMO, UN etc

Communication and application of drought warnings:

Effective communication and public participation will increase the quality and acceptance of the DEWS, since this: (a) ensures acceptance of or trust in the science that feeds into the planning; and (b) provides essential information and insights about drought preparedness, since the relevant wisdom is not limited to scientific specialists and public officials.



Participatory methods, such as interactive approaches, or structured dialogues, are recommended.

User requirements for drought warnings:

The main requirements for drought monitoring and forecasting systems in Africa can be summarised as follows:

- Seasonal forecasts which means forecasts with a lead time of 2 to 5 months depending on length of season;
- Reliable data for each system, level or resource, which should be preferably from a single source;
- Evidence of success rate of forecasts based on history to improve confidence of users should be included in forecasts;
- Predictions should be available at local scale (forecasts should zoom to areas which users can relate to);
- Users have experience with occurrence of rainfall, therefore the spatial scale for predictions should consider variability of rainfall;
- Easy to understand information (communicate risks of forecast clearly to enable users incorporate this information into their own risk management frameworks);
- Drought forecasts should include recommendations on how users should respond;
- A tool that translates forecasts into information on the availability of water in rivers and dams.

In Africa, the number of users of “state of the art” outputs is very small. The main challenges for drought forecasting and early warning systems in Africa are as follows:

- Early warning information where it exists is delivered on an occasion basis. End users do not get information in suitable format at the time they need it. Systems for disseminating or delivery or exchange of information in a timely manner are not well developed or inexistent, limiting their usefulness for decision support;
- Early warning information is often too technical, limiting its use by decision makers and farmers. End users are not involved in product verification. There are no customer’s/users networks to ensure product verification and service feedback;
- Early warning information is often unreliable on the seasonal timescale and lacks specificity, reducing their usefulness for agriculture and other sectors;
- Drought impact assessment methodologies are not standardized or widely available, which limits the formulation of regionally appropriate mitigation and response programs;



- Drought indices are generally inadequate even for detecting the onset and end of drought;
- Integration of information into government structures is poor and focuses on emergency response rather than long-term planning;
- Users are not aware of the range of early warning products that they can use.
- Lack of knowledge on how to manage the risks associated with the uncertainty of forecasts.
- The probability of a conditions/range of values is not easily understood at the application level of the forecast information as well as the implications. This leads to failure to interpret the information and convert it into actionable tasks/responses.

Early warning on food security to inform emergency food relief is important in Africa. Famine early warning systems and networks across Africa are coordinated by FEWSNET. These networks include regional, national and local vulnerability assessment committees. FEWSNET publishes a monthly bulletin on food security. Remote sensing and ground truthing techniques are applied in generating food security forecasts.

The potential of globally available drought forecasts and early warning data/information as well as knowledge of mitigation and adaptation measures as “state of the art” remains largely untapped.

Institutional Capacity

A clear institutional framework is important for assigning responsibilities for tasks to address the issues raised in this document. The institutional framework includes policies and guidelines that make it possible for people to intervene in an organised manner. An institutional framework is required to undertake the following tasks:

- a) Collect monitoring information from the local level and provide it to the forecasters at national/global level;
- b) To obtain and update user requirements;
- c) To downscale and package forecast and early warning information to suit user requirements;
- d) To monitor performance of forecast and mitigation information, obtain user feedback, and recommend updating of the information;
- e) Facilitate the flow of information between the national and local level



Institutions are trying to collaborate to combine skills available to improving the quality of the product. Effort has been made on water resources assessment in Africa and as well as hydrological modelling, data acquisition and compatibility for the use with various models.

In Africa the infrastructure for drought analysis is generally inadequate (equipment, computers, software, etc.) although a few organisations such as the CSIR in South Africa are better equipped the deployment of adequate human resources remains problematic. In addition financial resources are very limited. The consequence is that forecasting and early warning systems available in Africa are not adequately maintained and the products are not available on time.

There is limited availability of skilled scientists, technicians and support staff to operate drought early warning systems. So far, capacity building efforts have proven inadequate. 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.

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”, which results in unreliable product downscaling to regional and local levels. There is limited climate based monitoring, scientific analysis and research Funding for research programmes especially on water resources assessment, hydrological modelling, water accounting and data compatibility is inadequate.

There is a disconnection between available resources and responsibilities. “State of the art” suggests that improved distribution of responsibilities as follows:

- Level 1: Institutions involved in monitoring but some also provide forecast information;
- Level 2: Institutions responsible for resources management, public services or Earth observation;
- Level 3: Institutions that process data and provide information to the public. Institutions that collate data and maintain databases also fall into this category;
- Level 4: Institutions that develop monitoring and forecasting methods and tools.

The existing institutional arrangements for drought mitigation in Africa offer following opportunities:

- The framework for mobilization of government agencies exists and substantial resources can be brought together



- Institutional structures for implementation of drought mitigation and adaptation interventions exist
- The need for strategies to mitigate drought is generally appreciated and the need for drought early warning systems is also appreciated
- Communities are already engaged in activities to be able to survive future droughts and climate change

A financial and legal framework is required to:

- a) Manage uncertainties associated with forecast information when applied at the local level
- b) Mobilize finances to support implementation of mitigation measures
- c) Manage the legal consequences of lack of action or transfer of risks

It includes mechanisms to raise and distribute funds or materials (or food) and the laws and by-laws to enforce certain human behaviour in order to obtain the desired outcomes or prevent undesirable ones.

Policy Actions

This scientific research has generated the following messages which should be taken up by policy makers in the European context:

- Improvement/strengthening of the skill of forecasting products
- Transfer of knowledge from Europe to Africa and from Africa to Europe
- Support evolution of an institutional framework that allows for further improvement and application of drought forecasting products, sharing of data, technology and expertise
- More funding for research on certain emerging/promising topics for example forecasting products
- Improvement of data networks

The following are the main **targets**:

- European Commission; DG RTD, DG ENV, DG DEVCO and DG CLIMA
- European parliament (eventually STOA)



- UN; WMO in particular

The main messages from this research which needs to be taken up by policy makers in the African context consider improvements on the following:

- Institutional networks
- Data networks
- Early warning and mitigation actions
- Cooperation within Africa
- Understanding and mapping of vulnerability/risks is indispensable to a better preparedness
- Spatial resolution of early warning systems and updating intervals e.g. seasonal climate outlooks and monthly updates
- Integration of scientific and local knowledge based drought forecasting and monitoring systems
- Performance evaluation and institution capacitation at regional, national and local levels
- Improvement of link between relief efforts and development programmes
- Participation of stakeholders and water users
- Effective transfer of information to policy-and decision-makers
- Training and public awareness campaigns especially in situations where the country is approaching a drought season

The following are the main **targets**:

- At continental level the main targets are; AU, AMCOW, AMCEN
- At the regional level at the level of technical groups the main targets are; RBO's, Economic zones (SADC, ECOWAS, IGAD, etc), NELSAP (Nile Equatorial Lakes Subsidiary Action Program)
- National level; government ministries, department and agencies



- NGOs

Priorities may be established based in on such concerns as feasibility, effectiveness, cost, and equity. In choosing the appropriate actions, it might be helpful to ask some of the following questions:

- What are the cost/benefit ratios for the actions identified?
- Which actions does the general public deem feasible and appropriate?
- Which actions are sensitive to the local environment (i.e., sustainable practices)?
- Are your actions addressing the right combination of causes to adequately reduce the relevant impact?
- Are your actions addressing short-term and long-term solutions?
- Which actions would fairly represent the needs of affected individuals and groups?

A tool to rapidly assess the cost and benefits of mitigation actions should be implemented to help give effect to the vulnerability assessments.

The following aspects may be considered on the implementation process:

- Assess the availability of skilled human resources needed for drought preparedness planning
- Educate policy makers and the public on the need for improved drought preparedness as an integral part of water resources management
- Support creation of regional drought preparedness networks to enhance regional capacity in sharing lessons learned
- Enhance regional and international collaboration
- Recognize the role of WMO, ISDR, NMHSs, and regional/national institutions in drought early warning and preparedness



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LIST OF ABBREVIATIONS

AGRHYMET	Regional Training Centre for Agro-meteorology and Operational Hydrology
CAMELIS	Capacity Added by Mending Early and Livelihoods Information Systems
CARE	Cooperative for Assistance and Relief Everywhere
CFMSAMS	Crop and Food Supply Assessment Missions
CFSAMs	Crop and Food Supply Assessment Missions
CFU	Commercial Farmers Union
CGMS	Crop Growth Monitoring System
CICs	Community Information Centres
CILSS	Inter-State Committee for the Fight against Drought in the Sahel
CRTS	The Royal Center of Remote Sensing
DESA	Drought Emergency in Southern Africa
DESA	Drought Emergency in Southern Africa
DGH	General directorate of Hydraulics
DHA	Department of Humanitarian Affairs
DMC	Drought Monitoring Centre
DMN	National Directorate of Meteorology
DPA	Regional Directorates of Agriculture
DPPA	Disaster Prevention and Preparedness Agency
EAC	East African Community
EMOP	Emergency Operation
ENSO	El Niño – Southern Oscillation
EWRD	Early Warning and Response Directorate
EWWG	Early Warning Working Group
FAO	Food and Agricultural Organisation
FAO	United Nations, Food and Agricultural Organization
FEWSNET	Famine Early Warning Systems Network
FSAU	Food Security Analysis Unit
GIEWS	Global Information and Early Warning System on Food and Agriculture
GOR	Government of Rwanda
GTZ	German Agency for Technical Cooperation
HEA	Household Economy Approach
IFSHPC	Integrated Food Security and Humanitarian Phase Classification



IGEBU	Geographic Institute of Burundi
ILRI	International Livestock Research Institute
KWAMP	Kirehe Community-based Watershed Management Project
LEWS	Livestock Early Warning System
LIU	Livelihoods Integration Unit
LPCI	Livelihood Protection Cost Index
MAMF	Ministry of Agriculture and Maritime Fisheries
MINAGRI	Ministry of Agriculture
MINATTE	Ministère de l' Aménagement du Territoire, du Tourisme et de l'Environnement
MINITRANSCO	Ministrere des Transports et des Communications
MOH	Ministry of Health
NBCBN	Nile Basin Capacity Building Network
NC EW	National Committee for Early Warning
NCHS	National Center for Health Statistics
NEWU	National Early Warning Unit
NGOs	Non-Governmental Organizations
NISR	National Institute of Statistics of Rwanda
NMHS	National Meteorological and Hydrological Service
NUR	National University of Rwanda
OMS	World Health Organization
PAPSTA	Support Project to the Strategic Plan for the Agriculture Transformation
PARIMA	Pastoralist Risk Management Project
PLI	Pastoralist Livelihoods Initiatives
PRESAO	Seasonal rainfall forecasting in West Africa
RAB	Rwanda Agriculture Board
REMA	Rwanda Environmental Management Authority
REWU	Regional Early warning Unit
RMS	Rwanda Meteorological Service
RNRA	Rwanda Natural Resources Authority
ROA	Regional Offices of Agriculture
RRC	Relief and Rehabilitation Commission
RRSP	Regional Remote Sensing Project
SADC	Southern Africa Development Community
SADC	Southern Africa development community
SAP	Early Warning System



SARCOF	Southern Africa Regional Climate Outlook Forum
SAWS	South Africa Weather Services
SC-UK	Save the Children– United Kingdom
SPI	Standard Precipitation Indices
SPIAC	Prediction System of Information and Early Warning on floods in the Inner Niger
SPSS	Statistical Package for Social Sciences
SSD	Secretariat for the Drought Disaster
UN	United Nation
UNDP	United Nations, Development Programme
USAID	United States agency for International Development
USAID	United States of Agency International Development
VAC	Vulnerability Assessment Committees
VAM	Vulnerability Analysis Mapping
WB	World Bank

1 INTRODUCTION

This document fulfils the final aim of DEWFORA which is to put forward a framework for improving drought early warning, with more effective drought mitigation measures that strengthens preparedness, increasing resilience, and enhancing adaptation to drought in Africa through consolidating the findings from the different work packages (WPs) carried out on study. The linkages between these WPs are illustrated in Figure 1.

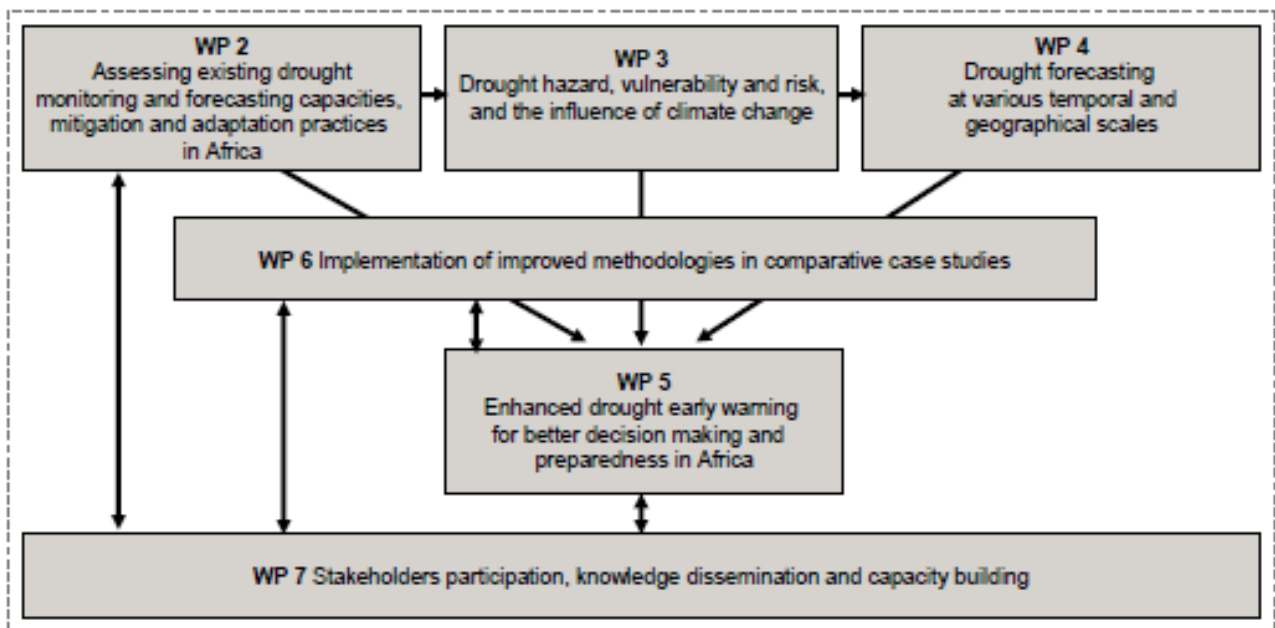


Figure 1-1 Contribution of WP2, 3, 4 and 6 to the framework for and guidelines for effective drought early warning and response in Africa

In Deliverable 5.1 (D5.1) the basic framework for improved drought warning and mitigation in Africa was established, outlining the main elements to be considered to get to a situation with improved drought warning and mitigation. This is followed by D5.2 which provides organizational charts to describe the institutional responsibilities, and communication lines for drought responses from national to local levels, derived from case study experiences. D5.3 is a guideline report, presenting the consolidated framework for drought forecasting, warning and mitigation from national to local scale. It includes the forecasting and the institutional frameworks. D5.4 will present recommendations for enhancing drought preparedness at the local, national and trans-boundary basin scales and coping with drought under a changing climate.

This document makes up deliverable D5.3. It provides a framework for drought warning and mitigation from national to local scale. This framework can be used as a guideline to supports drought early warning and more effective response in Africa by taking advantage of



advances in science and lessons from other parts of the world on technical and social organization. It is meant to support existing drought monitoring and warning institutions and agencies in the operation of drought early warning systems (DEWS).

1.1 OBJECTIVE

The main objective of this document to provide a guideline for a framework to downscale and package drought forecasts and produce early warning information suitable for application in defining implementable drought mitigation actions. The framework considers scientific advances in monitoring and forecasting at global, national and local levels. It also includes mechanism(s) to improve flow of this information to the local level from national to local scale to meet user preferences and provide actionable tasks/responses at the local level.



2 IMPORTANT DEFINITIONS

The following definitions apply to this document:

- **Drought** – a condition that originates from a deficiency of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector
- **Meteorological drought** – occurs when annual precipitation is between 70% and 85% of the long-term annual mean precipitation.
- **Hydrological drought** - a deficit in runoff in rivers, surface reservoirs and ground water
- **Agricultural drought** - a situation of inadequate soil moisture for rain-fed crops
- **Socio-economical** - a drought which results in social stress and economic hardships
- **Drought mitigation** – the reduction in the classification of a drought in terms of frequency and magnitude of risks and resulting from reduction of the potential impact of a drought
- **Drought adaptation** – a process of being able to survive in a drought condition. It refers to changes in processes, practices, and structures to moderate potential impacts of future drought.
- **Desertification** - a process of land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variation and human activities. Land degradation manifests itself through soil erosion, water scarcity, reduced agricultural productivity, loss of vegetation cover and biodiversity, drought and poverty.

3 AN EVIDENCE-BASED FRAMEWORK FOR DROUGHT EARLY WARNING SYSTEMS

Early warning systems can make a substantial contribution to overall drought damage reduction objectives by enabling institutions and vulnerable groups to take timely action to mitigate loss and damage in advance of an impending hazard event. Existing early warning systems have limitations in the science and institutional, social and legal aspects which affect their application (D2.4, D2.5). An evidence based framework can be used to identify these limitations and formulate possible solutions as policies, procedures and guidelines. The following critical questions were applied in this document to extract evidence from WP2, WP3 and WP4 as input to defining the framework for early warning systems:

- What is the science available? Evaluating the detection of the signs of impending drought. Definition of risk levels and analysing the signs of drought in an integrated vulnerability approach
- What are the societal capacities? Evaluating the institutional framework that enables policy development.
- How can science be translated into policy? Linking science indicators into the actions/interventions that society needs to implement. Evaluation of policy implementation and giving effect to early warning
- How can society benefit from the forecast? Evaluating the provision of information to potentially affected groups.

These four critical questions are illustrated in Figure 3-1.

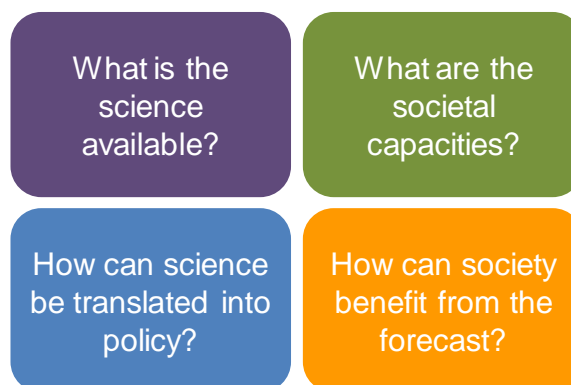


Figure 3-1: Critical questions to guide the development of an evidence-based framework for drought early warning systems

On this study evidence is drawn from selected river basins in Africa as case studies namely; the Oum-er-Rbia River Basin, (Morocco), Eastern Nile Basin (Burundi, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda), Limpopo Basin (Botswana, Mozambique, South Africa and Zimbabwe) and Niger Basin (Algeria, Benin, Burkina-Faso, Guinea, Ivory Coast, Mali, Niger and Nigeria). These basins are shown in Figure 3-2.

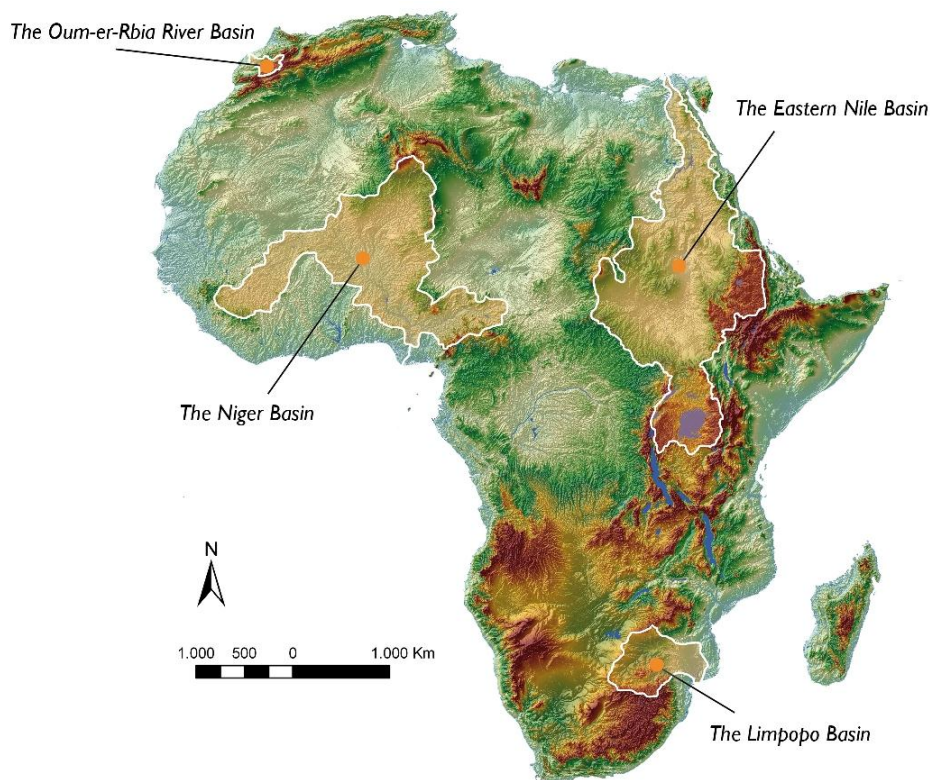


Figure 3-2: Location of case study basins-

Lessons are also drawn from systems, networks/ institutions and project divided into groups by Global systems, European systems which also cover Africa.

A summary of the findings from the investigations done on the different work packages on the DEWFORA project is provided in Annex A. The reader is referred to the specific deliverables for more detailed information.

4 WHAT IS THE SCIENCE AVAILABLE?

The analysis considers the well-established scientific processes for DEWS namely (i) identification and monitoring (ii) forecasting, (iii) warning and (iv) response (see Figure 2). The DEWS detects and evaluates the signs of impending drought, its magnitude, timing and duration and assigns risk levels. A drought early warning system should include measures to improve the societal response and thus reduce drought damage. For a locality or system “P” affected by drought, if unattended, a drought hazard can result in damage (drought damage). However the relationship between drought hazard and its potential drought damage can be changed by acting on the societal response. In order for these response actions to be effective they should consider the scientific information on the drought hazard coming from the DEWS processes.

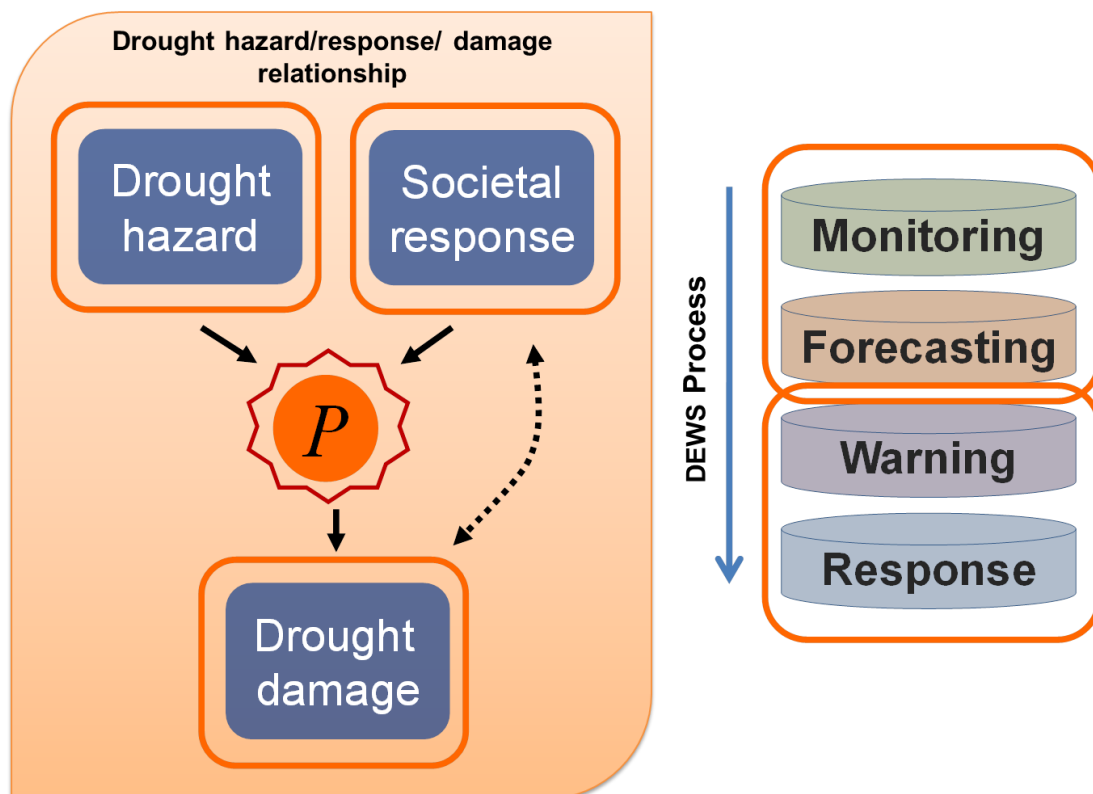


Figure 4-1 An illustration of the forecasting decision chain.

To improve the response process it is important to have means of measuring the *drought hazard*, potential and actual damage. It follows from the definition of drought in Chapter 2 of this document that the danger or threat of a drought (**drought hazard**) originates from a deficiency of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector. Taking from D3.1, nature-based determinants namely meteorological, hydrological and agro-ecosystems can be used as drought hazard indicators. Drought identification and monitoring requires **diagnostic** indicators while drought



early warning requires **predictive** indicators. The later may include information relative to the recent past.

On potential and actual drought damage more emphasis is placed on a system's capability to reduce the potential drought damage. This is referred to as **vulnerability**. It includes the set of parameters that describe the characteristics of a system to modify potential damage. It is a function of susceptibility and coping capacity and captures the societal response. Vulnerability assessment seeks to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. The inadequacies are addressed through response actions.

In the following sections the scientific processes for DEWS namely (i) identification and monitoring (ii) forecasting, (iii) warning and (iv) response are subjected to the four critical questions listed in Chapter 3 of this document, to extract evidence from WP2, WP3 and WP4 as input to defining the framework for early warning systems. We also pay special attention of scientific results obtained within the DEWFORA project.

4.1 DROUGHT IDENTIFICATION AND MONITORING

The identification and monitoring of drought monitoring using drought diagnostic parameters is a fundamental component of any DEWS. Diagnostic indicators already being applied to **detect** if a drought threat or hazard exists in Africa are described in Deliverable 2.1 (D2.1). The main ones can be summarised as follows:

Standardised Precipitation Index (SPI), Palmer Drought Severity Index (PDSI); deviation analysis, decile rainfall, surface water supply index (SWSI); drought hazard and drought vulnerability assessment and mapping, vegetation condition index (VCI), water satisfaction index (WSI), Normalised Difference Vegetation Index (NDVI), drought operating rules and storage forecast trajectories, flow deviation, agricultural drought threshold, veld/forest production and insect production

Of these parameters D2.1 also shows that SPI is a more common indicator.

Time series of a drought index data are decomposed into frequency components and the wave-like oscillations are analysed to understand the temporal variability of drought. This is referred to as wavelet analysis. The aggregation periods of 3, 6 and 12 months can be applied to detect drought as follows:

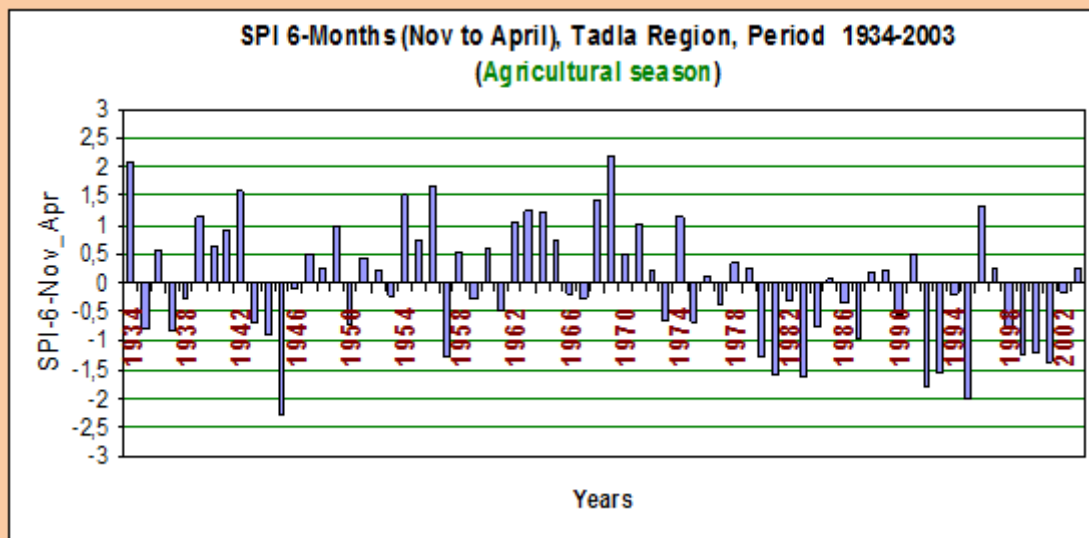
- 3-month SPI is associated with short- and medium-term moisture conditions associated with seasonal estimations of precipitation. However, a relatively normal 3-month period (or even wet) can occur during a long drought spell.
- 6-month SPI is associated with medium-term precipitation anomalies and is usually associated with anomalous stream flows and reservoir levels.
- 12-month SPI reflects long-term precipitation patterns that are associated with changes to large reservoirs and groundwater.

NDVI is affected by many ecological factors and water availability. NDVI response is expected when the water deficit reaches a certain minimum threshold, depending on vegetation type, time of the season etc. Analysing the relation of vegetation status and water deficit locally can improve drought warning systems by providing information on how drought indexes can be interpreted locally.

4.1.1 Example 1 – Oum er Rbia basin

(a) 6 month SPI

The following diagram shows the meteorological drought in Tadla region (Oum er Rbia basin) characterized using the 6month SPI (SPI-6) over the period 1934-2003 (ref D2.2).



Reference: Deliverable 4.6

These data show that the most severe drought episodes for the Tadla region (Oum Er Rbia basin) over the last seventy years are the 1940-45, 1957-1958, 1980-85, 1992-93, 1994-95 and 1998-2002 periods (Ouassou *et al.* 2007).

4.1.2 Example 2 – Limpopo River basin

(b) Standard Precipitation Index

- *With higher aggregation order, the SPI time series show less power (on the wavelet power spectrum) in shorter periods. For example,*
- *SPI1 time series has events within 4 to 16 months periodicity, but some of these were not present in the 18 month aggregation SPI.*
- *SPI1 and SPI18 have power in the higher period range of 32 to 64 months but longer periodicity is visible in the SPI18, but not in the SPI1.*
- *Wavelet coherence analysis shows that SPI3 shares signal properties with ENSO of periods between 2 and 4 years but these frequency coherencies are out of phase for the two time series. The power of frequency coherencies is not stable and changes over time and from one event to another. For 1987, ENSO and SPI3 time series show coherence power over a period range from 0.5 to 4 years. The 1992 drought shows a special wavelet coherence pattern with a distinct band of 4 years*

Reference: Deliverable 4.6

(c) Standardized Precipitation Evapotranspiration Index (SPEI)

- *13 SPEI principal components (PCs) explained 91 % of the total variation. The first 6 PCs sum up to 78 % of total variance. PC 1 shows a drought pattern with a strong south-western gradient. PC 2 shows an orthogonal north-western gradient but also has negative values along the coastline in the East. PC1 and PC2 account for 53 % of the total variation. PCs 3 to 5 contribute 8 %, 7% and 5 % to the total explained variation and exhibit more complex patterns. All three show patterns that divide the region in three. PC 5 had the highest correlation with all the climate anomaly indexes*

Reference: Deliverable 4.6

(d) Standardised Runoff Index (SRI)

The following is a summary of the results obtained on the Limpopo River Basin. Calculations of Standardized Runoff Index (SRI) were done using observed runoff data.

- *There was strong decrease in runoff in the Crocodile River between 1985 and 1995 and there was also a change in frequency of SRI with high power in the 16 to 32 month band.*
- *Low power was observed during the 80s and early 90s except for Mogalakwena River which retained power in the 32 month band. This could be connected to a change in the atmospheric systems' dynamic.*
- *During the 1985 to 1995 period the coherence or SRI with the Oceanic Nino Index (ONI) is broken for the Pienaars and Crocodile Rivers. Several events on the Pienaars River in the late 70 and late 90 show coherence with ONI in shorter periods of 4 years. The Crocodile River shows the same property in the late 90s with coherence power over a wide range of periods. The Mogalakwena River shows power on a longer period and high power in late 90s and it also has coherence power in lower periods during the early 80s*
- *Consistent bands of frequency coherence with ONI were often interrupted during the period 1985 to 1995.*
- *SRI for the Chokwe station exhibits high power in the 70s for periods between 2 and 5 years but in the period between 1985 and 1995 the coherence band is changed and narrowed.*

Reference: Deliverable 4.6

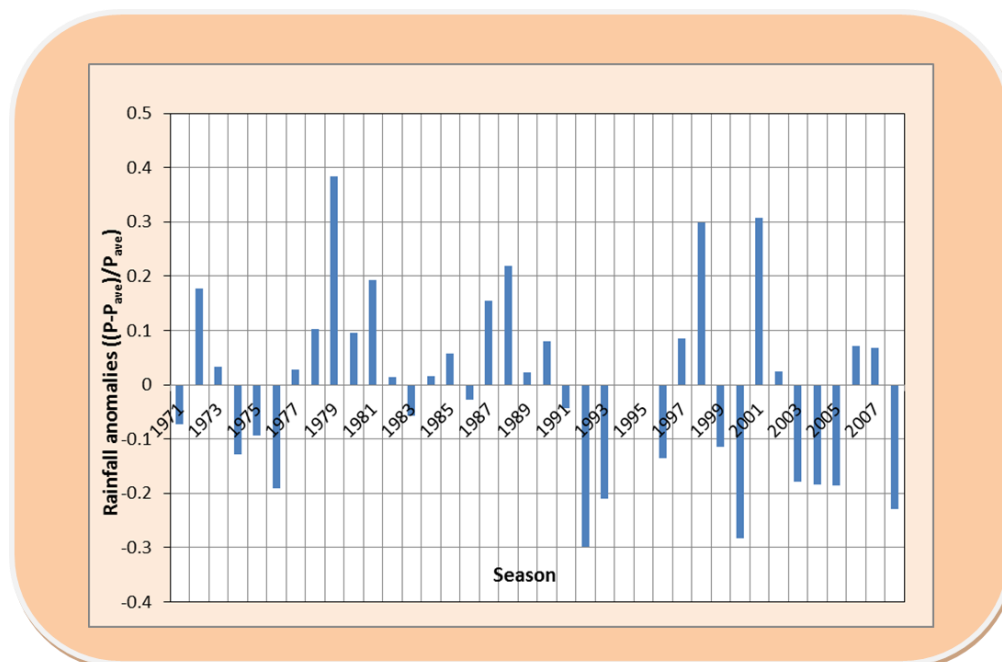
These results support the following conclusions

- The dominating spatial patterns cannot be linked to specific climate anomalies. Every drought event very likely is a unique combination of many factors of influence.
- Promising regions of SST were identified, which are potential predictors, as they exhibit lead times for the Limpopo region precipitation.
- Frequencies present in the signals had only little consistency in time and space. The period 1985 to 1995 is marked by strong changes in precipitation total and signal properties.

- Some flow stations seemed to be disconnected of the ENSO during this period and signal properties strongly differed between runoff stations, which indicates that every sub-catchment has local factors that affect rainfall anomaly and some regions can be affected more by an anomaly and others less.
- Prediction models have to be able to deal with nonlinear and interacting relationships with climate anomalies. Neither could certain anomalies be associated with spatial patterns nor could certain anomalies be isolated. It is very likely that every drought event is caused by a unique combination of different atmospheric anomalies
- Correlation and wavelet analysis were important methods but correlations between variables do not imply a causal link. Rather, causally linked variables are likely to be correlated. Hence, correlation can only serve as an indication of a potential causal and above all linear link. The same is valid for wavelet coherence analysis. Wavelet coherence does not imply a causally linked relationship, nor single event wise coherences, they only highlight signal similarities in frequency space. This can only be taken as an indicator for relationships between variables.
- Methods applied such as Wavelet analysis algorithms require complete records and cannot deal with missing data.
-

4.1.3 Example 3 – Eastern Nile River basin

The following rainfall anomalies for the period 1971 until 2008 were calculated for Kigali synoptic station, Rwanda:



Source: Rwanda Meteorological Service

4.1.4 Further evidence from DEWFORA

What are the most useful **diagnostic** indicators for drought hazard? There is no simple answer as indicators are sector/system/location specific. Indicators should be useful for application in defining actions to reduce vulnerability. For example, comparison of rainfall deficits for different areas to compare exposure to drought can be misleading as seen in Southern Africa where regions have very different climatology and ecology. SPI and the SPEI are better drought indicators for these conditions but how well do they represent the drought impact on vegetation? For them to be useful indicators should be calibrated with observed impacts, risk level, and targets related to the most appropriate actions. The use of multiple indicators is encouraged to account for spatial and temporal variability and loss of sensitivity or power.

An evaluation of drought indices in Africa performed in Deliverable 4.6 obtained the following conclusions:

- Most of the severe droughts in Southern Africa are associated with El Niño (Rouault, 2005).
- There are strong differences of the correlation of SPEI3 and NDVI throughout the Limpopo basin. High correlations are found in the south eastern transect whereas the correlation in the north east and in the southwest are lower. Low correlations can be caused by intense irrigation within a grid cell, and/or vegetation types.
- In the Limpopo River Basin, below a value of SPEI < -1 vegetation is affected by drought and this can be used as a drought threshold in drought early warning. However further research is required to develop a framework which incorporates such relationships to identify potential thresholds.

4.1.5 Availability of data

The availability of diagnostic data is one of the major challenges for drought forecasting in Africa. The timely diagnosis of a drought requires near-real time monitoring tools and these have to be carefully selected depending on region. Relevant hydro-meteorological parameters monitored include rainfall, temperature, flow, storage and evaporation.



In the recent years, a growing number of datasets is becoming available to improve the performance of drought monitoring systems. WP4 identified the following data on administrative areas and catchment boundaries and rivers:

- g) Countries - Global Administrative Areas database version 2.0 (GADM, <http://www.gadm.org/>) and the CIA World Data Bank II (<http://www.evl.uic.edu/pape/data/WDB/>).
- h) DEM produced from the Hydro1k Africa (USGS EROS Data Center 2006) and up-scaled to the model resolution of 0.05°
- i) Catchment boundaries and rivers - HydroSHEDS data set (<http://hydrosheds.cr.usgs.gov/>).

The following datasets have been identified in WP4 for drought monitoring and estimation of drought indicators:



- a) The Global Precipitation Climatology Centre version 4 (GPCCv4). GPCC based in rain-gauges.
- b) The NOAA Climate Prediction Centre (CPC) Merged Analysis of Precipitation (CMAP) applies data from a variety of satellites and gauges
- c) The Global Precipitation Climatology Project versions 2.1 and 2.2, CPCP blends data from a variety of satellites and gauges. Monthly precipitation is available since Jan 1979 to Dec 2010 on a 2.5x2.5 degrees grid.
- d) CAMSOPI merged dataset produced by the CPC combining satellite rainfall estimates from the Outgoing Long-wave Radiation (OLR) Precipitation Index (OPI) with ground-based rain gauge observations from the Climate Anomaly Monitoring System (CAMS). CAMSOPI merged dataset is available from January 1979 (2.5x2.5 degrees) at the CPC (ftp://ftp.cpc.ncep.noaa.gov/precip/data-req/cams_opi_v0208).
- e) ERA Interim (ERA-I) is the latest global atmospheric reanalysis covers the period from 1 January 1979 onwards (79x79km), with forward extension n near-real time <http://www.ecmwf.int/research/era>.
- f) ERA-I sea surface temperature (ERA-I –SST) and HADSST2 sea surface temperature anomaly data sets
- g) Runoff - Global Runoff Data Centre (GRDC, <http://www.bafg.de/GRDC>),
- h) Streamflow and dam storage, South Africa, Water Affairs <http://www.dwa.gov.za/Hydrology/>.
- i) Southern Oscillation Index (SOI), ENSO indexes (ERSST), ENSO indexes (OISST), Darwin sea level pressure (SLP), Tahiti SLP, North Atlantic Oscillation (NAO), Oceanic Nino Index (ONI) - CPC <http://www.cpc.ncep.noaa.gov/>
- j) Indian Ocean Dipole Mode Index (DMI), - Based on NOAA OISST Ver.2 - <http://www.jamstec.go.jp/frcgc/research/d1/iod/DATA/dmi.monthly.ascii>
- k) Trans Nino Index (TNI), NINO3.4 (HadSST) - : http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/
- l) World Digital Soil Map (FAO 2003), soil types to 0.05° x 0.05° grid cell
- m) Irrigated area within cell, water requirements and irrigation cropping patterns from the "Global map of irrigated areas" and FAO 1997



The meteorological data used in DEWFORA project includes: (i) the European Centre for Medium/Range Weather Forecasts (ECMWF) ERA-Interim (ERA-Interim) reanalysis and long-range weather forecasts, and (ii) the Council for Scientific and Industrial Research (CSIR) in South Africa conformal-cubic atmospheric model (CCAM) seasonal forecasting system. The following datasets are available from ECMWF from ERA-Interim global atmospheric reanalysis and long range forecasts:

- Atmosphere global forecasts
 - Forecast to ten days from 00 and 12 UTC at 16 km resolution and 91 levels (in 2011/12: ~137 levels).
- Ocean wave forecasts
 - Global forecast to ten days from 00 and 12 UTC at 28 km resolution
 - European waters 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 (to day 32 on Thursdays at 00 UTC, in 2011: also on Mondays + 46d on the 15th of each month)
 - 32 km resolution up to day 10, then 65 km, and 62 vertical levels (in 2011: ~95 levels);
 - 12 UTC with persisted SST up to day 15, 00 UTC with persisted SST up to day 10 and then coupled ocean model (in 2011 coupled both at 00 and 12 UTC);
 - Coupled ocean has horizontally varying resolution ($\frac{1}{3}$ to 1°), 29 vertical levels (in 2011 new ocean model NEMO and NEMOVAR DA);
 - Coupled wave mode.
- Seasonal forecasts: Atmosphere-ocean coupled model
 - 41-member global forecasts to seven months (in 2011: System 4); atmosphere: 120 km resolution, 62 levels (80km, 91 levels); ocean: horizontally-varying resolution ($\frac{1}{3}^\circ$ to 1°), 29 levels (NEMO and NEMOVAR)
 - e-forecast suite: 11 members x 25 years (15 members x 30 years, 1981-2005)
- Reanalysis:
 - Since January 1979 to present (near real time update);
 - Atmosphere: 80 km horizontal resolution with 62 vertical levels;
 - 6 hourly analysis, 12 hour 4D-Var assimilation;
 - 10 days forecasts (at 00 and 12 UTC).

In D4.2 and D4.3, the quality and availability of precipitation datasets for drought monitoring in Africa was analyzed. The following conclusions were drawn:



- There are four global precipitation datasets over Africa and ECMWF reanalysis highlights uncertainty associated with accurate estimates of precipitation for verifying purposes.
- A robust evaluation of seasonal forecasts is strongly dependent on the verification dataset. There is a high uncertainty of precipitation estimates over Africa.
- ERAI precipitation has limitations for drought applications, especially over the tropical rainforest, because of drifts in the model climate. However, in the other regions, it compares reasonably well with the remaining datasets and has the potential to be used as a monitoring tool because of its near real time update (in contrast with the other datasets). Furthermore, a robust evaluation of seasonal forecasts is dependent on the verification dataset. Since there is no clear information on which dataset is more reliable, the seasonal forecasts of precipitation were verified against GPCPv2.2.
- The ERAI configuration has a spectral T255 horizontal resolution (about $0.7^{\circ} \times 0.7^{\circ}$ in the grid-point space) with 60 model levels. For comparison purposes the previous ECWFM ERA40 reanalysis (Uppala et al. 2005) ($1.125^{\circ} \times 1.125^{\circ}$) was also included. A k-mean clustering algorithm to GPCPv2.1 in order to identify regions with homogeneous precipitation climatologies. The GPCP and CMAP datasets are available in a $2.5^{\circ} \times 2.5^{\circ}$ latitude/longitude grid while the other datasets have higher resolutions. There is a tendency of the reanalysis products (both ERAI and ERA40) to overestimate precipitation in the tropical rainforests.
- ERAI and GPCP precipitation datasets show good agreement in the mid-latitudes and poor correlation over the tropical regions in terms of precipitation estimates and spatial extent
- Drought monitoring relies on near real time observation of surface variables such as precipitation. Observations can either be derived through the merging of ground observations and remote sensing information or by using re-analysis tools.
- In-situ observations and suitable forecasting models are required for most of Africa

4.1.6 Information and knowledge management systems

Modelling and knowledge systems applied to provide drought early warning information or indices in Africa include global modelling systems, national modelling systems and local knowledge systems.

4.1.7 Where are the gaps?

As observed in WP2, monitoring of hydro-meteorological parameters is being undertaken by national institutions (meteorological, agricultural, and research institutions). For various reasons, including logistical, technical and financial, the spatial coverage of the monitoring network varies among the case study basins. The representativeness of the monitoring framework can be improved by encouraging local institutions, especially in populated areas, to monitor hydro-meteorological parameters and provide the information to national institutions. These local institutions could be schools/colleges/universities, hospitals/clinics, private enterprises, local government departments etc. *Observations can also merge ground observations and remote sensing information or by using re-analysis tools. In-situ observations and suitable forecasting models are required for most of Africa. It is important to take advantage of available Global datasets.*

4.2 DROUGHT FORECASTING

The main problem for developing effective early warning systems is the lack of means to predict climate conditions with sufficient skill and lead- time. Nevertheless, there has been remarkable progress in the science of climate and climate prediction in the last few decades that permits to mainstream the climate variable into the development planning. This requires an understanding of how climate variability impacts on society in a country, region, or community.

4.2.1 Example 1 – Limpopo River basin

A system to forecast crops has been in existence before 1980.

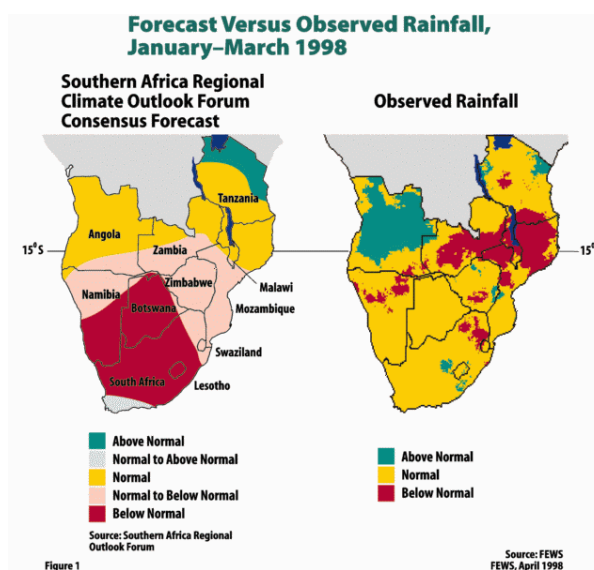


Figure 4-2: Forecast versus observed rainfall January to March 1998



4.2.2 Meteorological forecasting

The ECMWF maintains two currently operational ensemble forecasting systems through its Variable resolution Ensemble Prediction System (VarEPS): (i) weather forecasts out to 32 days and (ii) seasonal forecasting produces forecasts out to 7 months.

The time scale for medium-range (up to day 15) and monthly (up to 7 months) weather forecasting is too short for variations in the ocean significantly to affect the atmospheric circulation, hence it is essentially an atmospheric initial state problem. The ECMWF medium-range weather forecasting system is based on atmospheric-only integrations. The monthly forecasting system comprised the medium-range VAREPS in ocean-atmospheric coupled mode after day 10. The real-time VarEPS/monthly forecasting system is a 51-member ensemble of 32-day integrations. The first 10 days are performed at 0.28x0.28 degrees resolution forced by persisted SST anomalies (updated every 24 hours). After 10 days the model is coupled to the ocean model and has a resolution of 0.56x0.56 degrees. Drift is removed from the model solution during the post-processing. The probability distribution function (pdf) of the model climatology is evaluated to detect any significant difference between the ensemble distribution of the real-time forecast and climatology. The climatology is a 5-member ensemble of 32-day VarEPS/monthly integrations, starting on the same day and month as the real time forecast for each of the past 18 years.

Seasonal forecasting is less problematic than monthly forecasting because of the long predictability of the oceanic circulation (of the order of several months) and by the fact that the variability in tropical SSTs has a significant global impact on the atmospheric circulation. Since the oceanic circulation is a major source of predictability in the seasonal scale, the ECMWF seasonal forecasting system is based on coupled ocean-atmosphere integrations. Seasonal forecasting is also an initial value problem, but with much of the information contained in the initial state of the ocean. The principal aim of seasonal forecasting is to predict the range of values which is most likely to occur during the next season. The atmospheric component of the coupled model is the ECMWF IFS (Integrated Forecast System) model version 31r1. The horizontal resolution used for seasonal forecasts is 1.125x1.125 degrees. The seasonal forecasts consist of a 41 member ensemble. The ensemble is constructed by combining the 5-member ensemble ocean analysis with SST perturbations and the activation of stochastic physics. The forecasts run for 7 months. A set of re-forecasts (otherwise known as hindcasts or back integrations or just referred as climatology) are made starting on the 1st of every month for the years 1981-2005. The forecasts are available at the ECMWF data finder. Data are delivered in the GRIB format.



The application GRIB API3 can be used to read, write and manipulate that data format under an Apache Licence.

The Council for Scientific and Industrial Research (CSIR) in South Africa runs operationally a seasonal forecasting system based on the conformal-cubic atmospheric model (CCAM). CCAM is configured to generate a 28-year set of hindcasts as a result of forcing the CCAM with predicted, as opposed to persisted, SST anomalies. The ECHAM4.5-MOM3-DC2 (12 ensemble members; 74.25°S to 65.25°N) and ECHAM4.5-GML-CFSSST (12 ensemble members; 46°S to 46°N) forecasts data sets are available from January 1982 to present. The model data are obtained from the data library of the International Research Institute for Climate and Society. The observed SST data sets used are the 1°x1° resolution data of NOAA's OI.v2, and the 2°x2° resolution data of NOAA's NCDL ERSST version3b. A statistical model (canonical correlation analysis – CCA) which uses the most recent 3-month mean antecedent global ERSST field as predictor and the OI.v2 global SST as predicted from the two CGCMs. The three models produce a 28-year set of retro-active SST forecasts from 1982/83 to 2009/10 for lead-times up to 6 months. The retro-active forecasts average the three global forecasts to produce an equal weights set of multi-model forecasts. The same procedure is followed to produce forecasts operationally every month. The operational forecasts and verification statistics are presented on the website of the South African Risk and Vulnerability Atlas (<http://rava.qsens.net/>)

Seasonal forecasting provides a statistical summary of the weather events occurring in a given time period. Most of the precipitation over the African continent is controlled by the south to north and back displacement of the Inter Tropical Convergency Zone (ITCZ), the intensity of the low level Tropical Easterly Jet (TEJ) and the flow disturbances in the high level African Easterly Jet (AEJ). The rainfall field over West Africa is characterised by a zone of maximum precipitation that migrates north and south throughout the course of the year. This zone lies to the south of the ITCZ. For drought applications the timing of the rainy seasons, amount of precipitation and its interannual variability are important.

As an example, the case study of the integration of monitoring and forecasting for the recent 2010-11 drought in the Horn of Africa is presented. The 2010-11 drought in the Horn of Africa resulted from a precipitation deficit in both the Oct-Dec 2010 and Mar-May 2011 rainy seasons, and this was captured by ERAI. Soil moisture anomalies of ERAI also identified the onset of the drought condition early in Oct 2010 with a persistent drought still present in Sep 2011. The precipitation deficit in Oct-Dec 2010 was associated with a strong La Niña event. The ECMWF seasonal forecasts of NINO3.4 predicted the La Niña event from June 2010 onwards, and also a dry precipitation anomaly for the region from July 2010 onwards. On the



other hand, the seasonal forecasts for the Mar-May 2011 season did not predict the anomaly in advance, except for the forecasts in March 2011.

4.2.3 Performance of forecasts on the Oum-er-rbia, Blue Nile, Upper Niger, Congo and Limpopo River Basins

Performance of forecasting products was assessed in the following basins: Oum-er-rbia (OR), Blue Nile (NB), Upper Niger (NG) Congo (CG) and Limpopo (LP). The results are summarized below:

(a) Precipitation forecasts

Seasonal forecasting in the South and North West of Africa shows good agreement for all data sets, while there is a low agreement in Central Africa (between the +/- 20° parallels). Seasonal forecasting in the BN, LP and NG show higher reliability and skill in comparison with the Congo and Oum er-rbia

ECMWF seasonal forecasts have higher predictive skill than climatology for most regions.

CAMSOP1 is a merged dataset produced by the 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). In the BN ERAI shows a significant overestimation and CAMSOP1 is in good agreement with GPCP annual cycle of precipitation.

S4 forecasts overestimate precipitation in both BN and NG basins in the first forecast month with a reduction of the peak rainfall with lead time, showing the impact of model drift.

In the CG basin, ERAI, CAMSOP1 and S4 show an early peak rainfall in March (GPCP in April) and a latter peak in November (GPCP in October). ERAI generally overestimates precipitation in CG, while S4 overestimates its amplitude. From the mean annual cycle analysis, CG basins appear as the most problematic with timing errors in the rainy season, and amplitude problems in S4

In the LP and OR basins all datasets show a reasonable agreement, with an underestimation of the rainy season in OR, and S4 has a reduced drift on both basins.

In the BN and NG, the ERAI overestimation of precipitation is also reflected in higher inter-annual variability, while in the CG and LP there is a good agreement between ERAI, CAMSOP1 and GPCP. The underestimation of precipitation during winter in OR by all



datasets is also associated with lower inter-annual variability. The changes in variability with lead time in S4 are smaller than what was found for the mean annual cycle of precipitation.

In the BN and NG the temporal correlation of both ERAI and CAMSOPI compared with GPCP decays with increasing SPI time-scale. In all basins, except OR, GPCP has lower decay time scales and higher variance of white noise while ERAI has the higher time scales and lower white noise variance.

In the NG, both ERAI and CAMSOPI show an opposite trend to GPCP, with a wet period until 2000 and severe and long term drought in the last decade.

S4 precipitation forecasts in terms of the anomaly correlation coefficient (ACC) for the ensemble mean in the BN, LP and NG basins have skill up to 3 months lead time for the rainy seasons, while in the CG and OR basins S4 does not have skill.

S4 outperforms the climatological forecasts in the basins where the original seasonal forecasts of precipitation have skill, namely BN, LP and NG. In CG and OR, S4 has a similar skill to climatological forecasts CLM.

(b) SPI forecasts

There is good agreement between the GPCP derived SPI at time-scales higher than 5-6 months, for all calendar months except July, when compared with river discharge anomalies.

SPI derived from ERAI and CAMSOPI compared with stream-flow shows much lower or no-existent the correlations. This reflects the poor intra-seasonal to inter-annual variability of precipitation of the ERAI and CAMSOPI datasets in the NG region

Taking moderate to severe droughts with an SPI below -0.8, for the SPI-6 the ROC of CLM is close to 0.5 (no information), while with S4 the ROC is higher close to 0.7 in the BN, LP and NG, 0.6 in CG and 0.54 in OR. For the SPI-12 the ROC of climatology is always above 0.5, since the climatological forecast inherits 6 months of monitoring. In this case, it is difficult to beat the climate forecast, but S4 outperforms climatology in the BN, LP and NG river basins (as documented before).

There is a significant drop in the ACC, especially in the BN, CG and NG river basins. CAMSOPI has problems in representing the intra-seasonal to inter-annual variability of precipitation. These problems are present during the monitoring periods and are extended to the forecast period. The quality of monitoring products is very important as they control the skill of the SPI forecasts for accumulation time scales.



Seasonal forecasts of the 1991/92 drought in the LP basin with different initial forecast dates starting August 1991 to July 1992, comparing the SPI-12 from GPCP (verification), CAMSOPI (monitoring) and the S4 and CLM forecast show that skill improves around Nov – Dec for and CLM performs better from Dec onwards.

(c) Hydrological forecasting

Hydrological forecasting usually requires a hydrological model to transform the meteorological forecast into hydrological predictions. The selection of a suitable hydrological model, or a combination of models, for the objective of drought forecasting in Africa was carried out by assessing various models using the following set of criteria.

- Represented processes and fluxes: interception, evaporation, snow, soil, groundwater, runoff, reservoirs, lakes, routing, water use, energy balance and calibration parameters
- Model applicability to African climatic conditions and physiographic settings: Applicability of the model in semi-arid regions
- Data requirements and resolution of the model (spatial and temporal resolution) meteorological, spatial, temporary. A fixed grid size and fixed basin sizes can limit model applicability. Model should be scalable
- Capability of the model to be downscaled to a river basin scale
- Continuous, operational models for drought early warning system at large scales
- Open source and well documented models are preferred

Two types of models were considered: Global Land Surface Models (GLSMs), that describe the vertical exchange of heat and water and Global Hydrological Models (GHMs) that describe water resources and lateral transfer of water. In total six GLSMs and eleven GHMs were evaluated. Emphasis was put on assessment of models on status of documentation on models, available data vs data requirements, ability to provide useful output for specific hydrological drought conditions and specific characteristics of focus areas, development status of model, open source vs proprietary software. In Africa there are many regions with a lack of good precipitation observations, and this is a limiting factor to application of data intensive models. Most models did not succeed in representing the water balance components in arid and semi-arid basins where there was the largest coefficient of variation (CV) of the global evaporation and runoff. Evapotranspiration, soil moisture changes, groundwater flow and surface water-groundwater interactions including wetlands are important for most catchments in Africa. The existing models are dominated by different processes and therefore show significant differences in their water-balance components and response to events.



The result of the analysis was that PCR-GLOBWB, SWIM, GWAVA, HTESEL, LISFLOOD and SWAT show higher potential and suitability for hydrological drought forecasting in Africa, although the differences in results suggest the need to use multiple hydrological models.

Two hydrological models were selected to test their application to Limpopo and Niger case study basins namely PC Raster Global Water Balance Model (PCR-GLOBWB) and the Soil and Water Integrated Model (SWIM). These results are presented in the following section.

i) Limpopo basin

The PC Raster Global Water Balance Model (PCR-GLOBWB) was applied to the Limpopo basin. Model parameters were assumed to be correct based on the best available input data. The difference that different ensembles of meteorological forecasts may bring in hydrological model results can be expected to dominate any gains that may be achieved by calibrating the model with one set of historic data.

New development includes an irrigation scheme to account for the highly modified hydrology in the Limpopo river basin. The model is set up for a spatial resolution of 0.05 x 0.05 degrees downscaled from 0.5 x 0.5 degrees and simulation is carried out for a 32 year-period on a daily time step. Part of groundwater drained by surface water is computed by assuming a linear relationship between the storage and outflow. Groundwater residence time depends on the saturated hydraulic conductivity of the aquifer the drainage porosity, the aquifer depth, and the drainage length. River routing is based on the kinematic wave approximation of the Saint-Venant Equation. Floodplains and through-flow wetlands are treated as regular river stretches except that flooding spans through the entire floodplain normally with higher resistance, which is defined in terms of Manning's n separately for the river bed and floodplain. Areas of lakes and floodplains are kept constant while routing. Irrigation water requirement for a cell is supplied through the storage of freshwater in the cell and groundwater extraction for irrigation is not considered but is feasible if information is available

Model output included actual evaporation; soil moisture; surface and subsurface runoff, river discharge, root stress, water storage in the three layers etc. Standardized Runoff Index (SRI) could not be computed for gauge stations in the Limpopo River Basin because the runoff data was not continuous during the required period of at least 30 years. Missing data reduces continuous measured data in general to about 10 years. The Streamflow Drought Index (SDI) applies estimates of natural logarithms of cumulative streamflow with mean and standard deviation. The index ranges from 0.0 (no drought) to -2.0 (extreme drought). The SDI allows the computation even if there are missing values. Similar SDI and SRI were obtained for 6 and 12 months, most flow occurs in the first 6 wet months of the hydrological



year. In both cases the major droughts appear to be identified reasonably well (1982-83, 1991-92) with SDI and SRI values smaller than -1.5. Extremely wet year of 2000 is very visible with SDI and SRI higher than 2.0.

ii) Niger River basin

The Soil and Water Integrated Model (SWIM) was set-up on the Intermediate Niger Basin and calibrated to represent region specific processes, stocks and fluxes by using regional ground-truth and remote sensing data. Further developments include reservoir management, wetlands and inundation plain dynamics. In the INB interaction between wetlands and lakes and inundation are important. The reservoir module allows for release for minimum flows, managed releases and energy releases.

Hydrological response units have same properties (soil and land use/cover) regarding biophysical processes. The model is connected to meteorological, land-use, soil, vegetation and agricultural management input data. Simulations consider water balance for four control volumes: the soil surface, the root zone, the shallow aquifer, and the deep aquifer. The percolation from the soil profile is assumed to recharge the shallow aquifer. Return flow from the shallow aquifer contributes to the streamflow. Shallow aquifer water balance includes ground water recharge, capillary rise, lateral flow, and deep percolation. The inundation module simulates release and flooding, the flooded surface area, inundation depths, and duration, evapotranspiration and percolation.

Model calibration and validation was performed with PEST (Model-Independent Parameter Estimation and Uncertainty Analysis) for period 1971-1980 and 1982-2000. The model performed well on estimation of runoff and flow frequency. An overestimation of the annual peak and over-estimation of low flows was obtained. The model is currently being extended to model drought conditions.

(d) Downscaling forecasts

Global institutions are better resourced to generate forecast and early warning at a broad scale. The simulated forecasts from the Global institutions are passed onto national institutions for further **downscaling** and **packaging** to meet local preferences.

The downscaling would include increasing spatial resolution to provide forecast information at lower levels such provinces, municipalities, districts, agricultural regions etc.

(e) Local indigenous knowledge forecasting systems

”Scientific” drought forecasting (SDF) methods apply Global Circulation Models (GCMs) but downscaling to local level has proved to be a huge challenge mainly because of inadequate calibration data, failure to accommodate local climate circulation systems and variations in geophysical conditions. Local knowledge drought forecasting (LKDF) systems accommodate these aspects but they are poorly documented, lack scientific validation and their applicability over large areas have not been tested. LKDF system forecasts compared well with what the season turned out to be.

Traditional indicators of drought in the Mzingwane sub-basin based on trees and plants are as follows:

Local Name	English Name	Scientific Name	Observation	Observation Period	Prediction	Comments
1.Umtopi		<i>Boscia albitrunca</i>	Less fruits	Sept to Oct	Below normal rains	Long term seasonal forecast
2.Uphane	Mopane	<i>Colophospermum mopane</i>	Too many flowers and green leaves(blooming)	Sept to Dec	Below normal rains and Drought year	Long term seasonal
3.Umevha(ugagu)	Thorny trees	<i>Acacia</i>	Ever green and too many leaves	Nov to Dec	Below normal rains and Drought year	
4.Umusu			Blooming	Dec to Jan	Onset of rains	Seasonal
5.Umganu	Marula	<i>Sclerocarya caffra</i>	Drying of leaves and many fruits		Drought	
6.Munembenembe			Less flowers	Sept to Nov.	Drought	Seasonal
7.Mukakate			Many seeds	July to Aug.	Abundant rains	
8.Mtetwa			Bares little or no fruits at all	Nov to March	Drought year	Long term and seasonal
9. Umhagawuwe		<i>Securinega virosa</i>	Less fruits	Nov to March	Below normal rain	Long term seasonal forecast
10.Mundamukwa			More flowers and fruits	May to July	Abundant rain	Seasonal
11.Isigangatsha		<i>Lannea discolor</i>	Too many flowers and green leaves(blooming)	Sept to Dec	Normal to above normal	Long term seasonal
12.Xakuxaku	Snot Apple	<i>Azanza garckeana</i>	Too many leaves and fruits	November to December. Fruits in June and July.	Below normal rains and Drought year	Long term
13.Umtshekisani			Too many flowers and fruits	Sept to Nov	Onset of rains	Seasonal
14.Umhlonhlo			Produces pink and white flowers	Sept to Nov	Drought	Seasonal

Traditional indicators of drought in the Mzingwane sub-basin based on insects, birds and animals

Local Name	English Name	Scientific Name	Observation	Observation Period	Prediction	Comments
1.Inkomo	Cattle		Breed less and abortion		Drought year	Long term
4.Macimbi	Mopane moths/ worms	<i>Coimbrasia belina</i>	Less in numbers	April	Drought year	
5.Umalulwani	bats	<i>Chiroptera</i>	Frequently flying	Rainy season	Imminent rains	Short term
6.Inkanku	Jacobin Cuckoo	<i>Clamator jacobinus</i>	Sings a lot	Rainy season	Abundant rains imminent	Long term
7.Amagen'a	Ants		Moving in a file and loading grass and food to their holes	Rainy season	Short term	Short term
8.Isingizi	Ground hornbill	<i>Bucorvus leadbeateri</i>	Sings a lot	May to June	Normal rain imminent	Short term
9.Intotoviyane	Locust	<i>Caelifera</i>	Seen in large numbers	Aug to Oct	Normal to above rainfall season	Long term
10.Ikonjani	Blue swallow	<i>Hirundo atrocaerulea</i>	Appearance	November to December	Imminent rains	Short term

Traditional indicators of drought in the Mzingwane sub-basin based on the sun, moon and wind are as follows:

Local Name	English Name	Scientific Name	Observation	Observation Period	Prediction	Comments
1.Isikhudumezi	heat	<i>n/a</i>	Too much heat	Aug-Oct	Imminent rainfall	Short term
2.Umoya	Southerly winds	<i>n/a</i>	blowing	Sept to Oct	Drought	seasonal
	West to east winds	<i>n/a</i>	blowing	July to Sept	Normal rains	Both short term and long term
3.Inyanga	Moon	<i>n/a</i>	Big circle around the moon	Jul to Sept	Abundant rains	Seasonal
4.Isavunguzane	Whirl wind	<i>n/a</i>	Blowing a lot, high frequency of occurrence	Aug to Sept	Abundant rains	Seasonal
5.Ungqwaqwani	frost	<i>n/a</i>	If it doesn't appear	June to July	Drought	Seasonal
6.Amazolo	Morning dew	<i>n/a</i>	Appear in the morning	Nov to Dec	Imminent rains in a day to three days	Short term

The hind-cast comparison applied seasonal rainfall, wind, NDVI and temperature data for 2011/12 and 2012/13 because lack of historical data for LKDF systems. LKDF system forecasts were compared with downscaled GCM forecasts as seasonal and monthly outlook forecasts provided by SARCOF, the SADC Climate Services Department and the Zimbabwe Meteorological Services Department. Results show a strong correlation between traditional



plant and tree indicators with resulting conditions captured as NDVI and indices based on observed rainfall, wind and temperature. Traditional forecasts performed better than downscaled GCM forecasts at local level for the 2012/13 season. The challenge is to isolate, enumerate and then verify LKDF parameters which were mainly based on personal opinions of the forecasters.

(f) Accuracy and reliability of forecasts

D4.2 acknowledges that while uncertainty in all the forcing data (mainly rainfall forecasts and perhaps temperature forecasts as well) can be minimised with the ensemble approach, hydrological models compound it by their inability to represent hydrological fluxes and the lack of good precipitation observations hydrological droughts. Thus further scientific advances on hydrological models that can use the seasonal forecasts to generate information for water management strategies in Africa.

Drought early systems based on local knowledge identified in D2.3 provide early warning on on-set of drought with varied lead times and overall period of seasonal outlook. Historical forecasts have not communicated the duration, magnitude and chance of occurrence of the drought. Evidence of consistent issuing of warnings is poor because of lack of documentation and this has limited the scientific advancement of these knowledge systems.

While the application of stochastically generated forecast trajectories (flow and storage), historical statistics (rainfall, flow and storage) and cyclical behaviour (rainfall and flow) for drought early warning are the preferred options by water managers in Africa as they offer improved confidence through learning from historical patterns there is an appreciation that future patterns may be different hence the need for new methods that incorporate seasonal forecasts (D2.3).

4.3 DROUGHT EARLY WARNING

Early warning information is derived from forecasting products. Examples of early warning systems in each of the case study basins are given in this section.

4.3.1 Example 1 – Oum er Rbia basin

In Morocco the institutions which provide early warnings were as follows:

- *The Royal Centre for Remote Sensing which provided monthly maps*



- *The Secretariat of State in charge of Water and the Environment provided estimates of water resources for the forthcoming hydrological year (starting in September). Water was allocated according to availability at the end of the raining season*
- *The National Directorate of Meteorology, Seasonal provided long-term forecast of precipitation using large scale climate patterns such as the SST, NAO and ENSO.*
- *The Ministry of Agriculture and Maritime Fisheries provided an overview of the rainfall situation by comparison to the normal year*

Morocco **the indigenous or local knowledge drought early warning** includes local observations communicated using adages or proverbs. The following are applied from mid-September to mid-March.

Period/Season - International Year (Moroccan/ Arabo-Berber, Agricultural year)	Observations	Adage
14 Sept to 13 Oct (Ctember)	Cold/Warm/Hot	If gets cold in autumn, both strong and weak could perish.
	Rainfall	Autumn rainfall won't bring any guest.
	Water level in wells	
	Size of figs	If fig's leaf size become like that of the mouse, the length of the day equals that of the night.
14 Nov to 13 Dec (Wamber)	Stars	Who wants to store wheat grain for the next year should sow it in November.
		If three bright stars rise up in the evening in a vertical line, speed up cereal seeding and say the growing season is over
		Tillage without manure is like a massage without news. At this time, only barley could be seeded as wheat could be eaten by birds.
14 Dec to 11 Jan (Jember)	Cold/Warm/Hot, Rainfall	The cold of December can reach liver.
		The cold of December makes bride looks like a monkey and the elderly like a skin. If the sun rises red, attach your donkeys and rest, and when the sky looks red, prepare your donkeys for a walk <i>Saad Akl Boulaa</i> , the sky is raining and the soil is absorbing.
12 Jan to 13 Feb (Yennayer)	Cold/Warm/Hot, Rainfall	In <i>Saad Al Boulaa</i> , feed a person he won't be satiated, and call him he won't hear you. This means that the cold is causing appetite increase and makes a person less reactive.
		Rain in February is a cure to all ills (of agriculture).
14 Feb to 13 March (Furar)	Cold/Warm/Hot, Rainfall	In February, rain is generally pouring in large amounts.
		In February (the laughter), one sometime it is sunny & sometime it raining.
		The leave of "Layalli" (period of extreme cold) is a grace, and the leave of Smaym (period of extreme heat) is an indignation.
		During the period of "Lyalli", early sowing (Bakri) is like late sowing (Mazouzi). If it rains in March, fields blossom even it they were growing poorly.

The following warnings are applied from mid-March to mid-September.



Period/Season - International Year (Moroccan/ Arabo-Berber, Agricultural year)	Observations	Adage
14 March to 13 April (Meyres)	Rainfall, Rain and sunny days	<p>The rain in March has the same impact as that of the rest of the year.</p> <p>March, talking to the other months: if I am present (if March is rainy), you can all disappear, but if I am absent (no rain in March), you have to be all present (it should rain in all the other months to compensate March's rain).</p> <p>If it is raining in March, if April isn't too sunny, and the skies are clear in May, the third of harvest could be saved for the next year even for the servile farmer who doesn't have land.</p> <p>Every tree should be planted before March, and all seeds should be seeded before Hayan (Ayyam alhoussoum).</p> <p>Don't count your baby's goat among other baby's goat until Hayyan days are over (Ayyam alhoussoum). This means that the cool weather and the scarcity of feed can kill baby goat.</p> <p>Ears always develop after Lyalli Hayyan had elapsed.</p> <p>In Batn Al Hout, it should rain or we die.</p> <p>Rainy and sunny days alternate in April until ears come up from the cereal flag leaf.</p>
14 April to 13 May (Ibrir)	Rainfall, Cold/Warm/Hot	<p>April's cold makes the boar shaking. This means that the temperature may rise in April, but it can drop suddenly.</p> <p>If it doesn't rain in April, my teeths become like the axes, and my eyes as big as the cup. This means that the people are afraid to have a low harvest.</p> <p>When May arrives, the orphans become independent. This means that with the warm temperature, the food becomes abundant and finding a shelter isn't a problem.</p>
14 May to 13 June (Mayyu)	Cold/Warm/Hot	<p>In May, bring your sickle and get prepared for cereal grain harvest.</p> <p>If the sky is clear the third of harvest will be stored in the next year.</p> <p>In May, you can harvest cereals even if they are still green.</p> <p>If it rains in May, you can seed maize and be sure that the yield will be good.</p> <p>Leave the letter R (months not comprising the letter R in Arabic) and you can sleep outside under the sky.</p> <p>Summer cold is sharper than he sword.</p> <p>Figs become ripe from the inside.</p>
14 Aug to 13 Sept (Yust ou Awussu)	Thunder and lightning, Figs	<p>The beginning and the end of August are mudd.</p> <p>If thunder, which is the sound made by lightning takes place in August, use all your capital to buy livestock.</p> <p>If there is thunder in Smaim, the illness strikes either women or livestock.</p> <p>When figs are ripe, the mudd is close.</p>

Period or Season - International Year (Moroccan/ Arabo-Berber, Agricultural year)	Adages/Observations
14 March to 13 April (Meyres)	<p>The rain in March has the same impact as that of the rest of the year.</p> <p>March, talking to the other months: if I am present (if March is rainy), you can all disappear, but if I am absent (no rain in March), you have to be all present (it should rain in all the other months to compensate March's rain).</p> <p>If it is raining in March, if April isn't too sunny, and the skies are clear in May, the third of harvest could be saved for the next year even for the servile farmer who doesn't have land.</p> <p>Every tree should be planted before March, and all seeds should be seeded before Hayan (Ayyam alhoussoum).</p> <p>Don't count your baby's goat among other baby's goat until Hayyan days are over (Ayyam alhoussoum). This means that the cool weather and the scarcity of feed can kill baby goat.</p> <p>Ears always develop after Lyalli Hayyan had elapsed.</p> <p>In Batn Al Hout, it should rain or we die.</p> <p>Rainy and sunny days alternate in April until ears come up from the cereal flag leaf.</p>
14 April to 13 May (Ibrir)	<p>April's cold makes the boar shaking. This means that the temperature may rise in April, but it can drop suddenly.</p> <p>If it doesn't rain in April, my teeths become like the axes, and my eyes as big as the cup. This means that the people are afraid to have a low harvest.</p> <p>When May arrives, the orphans become independent. This means that with the warm temperature, the food becomes abundant and finding a shelter isn't a problem.</p>
14 May to 13 June (Mayyu)	<p>In May, bring your sickle and get prepared for cereal grain harvest.</p> <p>If the sky is clear the third of harvest will be stored in the next year.</p> <p>In May, you can harvest cereals even if they are still green.</p> <p>If it rains in May, you can seed maize and be sure that the yield will be good.</p> <p>Leave the letter R (months not comprising the letter R in Arabic) and you can sleep outside under the sky.</p> <p>Summer cold is sharper than he sword.</p> <p>Figs become ripe from the inside.</p>
14 Aug to 13 Sept (Yust ou Awussu)	<p>The beginning and the end of August are mudd.</p> <p>If thunder, which is the sound made by lightning takes place in August, use all your capital to buy livestock.</p> <p>If there is thunder in Smaim, the illness strikes either women or livestock.</p> <p>When figs are ripe, the mudd is close.</p>

The following proverbs applied used as drought early warning.

Proverb/adage based on local knowledge	Description/Interpretation
Barley says: this is <i>Ntah</i> , irrigate me or I will fall.	Thin clouds are a promise for rain.
Warm sun is expelled.	Warm sun is followed by rain.
If it gets warm during summer, it will get cold in winter.	Warm summer is followed by cool winter.
If you notice fog, cereal will mature.	Fog will hasten cereal maturity.
If there is fog, take your kids to the forest.	Early fog during the day means the day will be warm.
As wind is strong, rain will be abundant.	Strong wind will bring abundant rain.
Don't trust fire if it is extinct, and don't trust blue skies during <i>Lyalli</i> season.	It may rain, even if the skies are blue in <i>Lyalli</i> season.
Don't take for granted guest's words and stars during <i>Lyalli</i> season.	Even if the sky is clear, rain may fall during <i>Lyalli</i> season.
Clouds are better than clear skies during <i>Lyalli</i> season.	Clouds help keep warmth while clear skies are responsible for cold nights as heat will be lost to the sky.
If you eat figs, buy yourself a <i>burnous</i> .	When figs are mature, it is time to get prepared to the cold season.
If fig is mature, be prepared to the rainy season.	When fig is mature, the rainy season is getting close.
If you see ripe figs, wait for the mud.	When fig is mature, the rainy season is getting close.
If the Heron shows up, the rain is close.	The arrivals of herons, means that rainy season is close.
If <i>Lyalli</i> season arrives, ask the vine tree, and if it is out, ask the vine tree.	Cold weather during <i>Lyalli</i> season makes vine tree to stop growing, and when it leaves, vine starts to re-grow.
When vine leaves have the size of mouse's ears, the length of the day is equal to that's of the night.	Equinox corresponds to the time when vine leaves have the size of mouse's ears.

4.3.2 Example 2 – Niger River basin

In West Africa for the Niger Basin in Mali the following institutions provided early warning: AGRHYMET, National Directorate of Hydrology, National Directorate of Meteorology, National Directorate of Agricultural Engineering, National Department of Agriculture, Institute of Geography of Mali, National Directorate of Environment and NGOs.

4.3.3 Example 3 – Limpopo River basin

In the Southern Africa, since 1997 the Southern Africa Regional Climate Outlook Forum has been bringing together national, regional, and international weather experts to build a consensus seasonal forecast for the region. The outlook has been provided as maps of expectation of above normal, normal and below normal rainfall.

The lead time for the precipitation forecasts has varied from a few days to a month in most study areas and in Southern Africa a lead of 5months has been applied by the South Africa Weather Services while the Southern Africa Regional Climate Outlook Forum (SARCOF) issues a 6months ahead forecast.

4.3.4 Example 4 – Eastern Nile River basin

In the Nile Basin-Equatorial Lakes Region national meteorological services provided weather forecasts and outlooks, including pre-season climate outlooks. In the Ethiopian Plateau non-governmental organisations (NGOs) were responsible at the national level for early warning



activities. In the East Africa Nile basin the RIBASIM-Nile was applied in the Nile Forecasting System to assess impacts of upstream developments along the Nile River. The Sudan Meteorological Authority produced rainfall forecasts for two to three month before the rainy season.

4.3.5 Drought early warning framework

The analysis of drought warning thresholds requires the simultaneous consideration of drought hazards and impacts. The following steps should be addressed: (i) define hazard (meteorological or hydrological etc); (ii) define the impacts in agriculture, water, ecosystems, health, etc; (iii) define exposure (number of people affected); and (iv) define coping capacity or adaptive capacity.

In order to define warning thresholds, research needs to focus on analyzing how socioeconomic systems respond to drought conditions. Figure 3 shows an illustrative example. We assume that response of the system under analysis can be characterized in probabilistic terms through an indicative variable (for instance, probability distribution of crop productivity) as a function of different drought states (for instance, wet, normal and dry conditions). The "coping range" of society may be described as the maximum perturbation from mean conditions that can be accepted without significant damages. In normal conditions, there is a coping range for the system that marks the acceptable values of the indicative variable (between LT_b and UT_b). If a drought forecast is available, the estimation of the probability distribution of the indicative variable gets shifted to a drier state, and the probability of being exposed to impacts increases with respect to the normal condition. The drought warning decision should be based on whether that probability increase is high enough to adopt a response action to mitigate the expected damages.

The problem can be addressed through classical cost-benefit analysis, but forecast uncertainty and skill introduce additional complexities that need to be carefully analyzed.

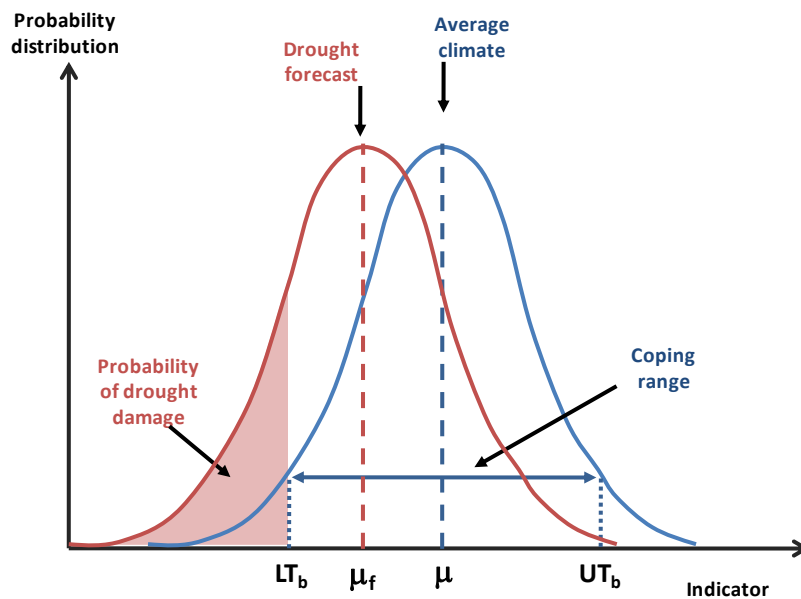


Figure 4-3 An illustration of activation of drought warning thresholds.

The applicability of this framework was tested in the case studies and the results were incorporated in this early warning protocol. The indicative variables suggested for case study areas are the following:

- Oum-er- Rbia Basin: Stream flow, crop, yield, rainfall, adaptive capacity, exposure
- Niger River Basin: Precipitation, stream flow, reservoir operation, state of ecosystems, adaptive capacity, exposure
- Limpopo River Basin: Precipitation, stream flow, crop, yields, management, rules, institutional, response, adaptive capacity, exposure
- Eastern Nile Basin: Hydrological indicators, adaptive capacity, exposure
- Pan- African Level Extreme forecast indices, precipitation, SPI

For the Limpopo basin case study, available data consisted on yellow and white maize yield data obtained from the South African National Department of Agriculture, Directorate: Statistics and Economic Analysis. Data are available from 1981 to 2011. The analysis was focused on Witbank and Middelburg agricultural districts and the Rustenburg agricultural district. Forecasts were taken from ECMWF System 4 data.

For the Oum-er-Rbia basin case study, available data consisted on durum wheat crop yield: 2 stations in the coastal region, 4 stations in plains and 3 stations in the mountains. Data are available form 1979-80 through 2007-2008. Sowing dates in the region are: October-



November, November-December or February. Harvest dates are: May, May-June or August. Forecasts were taken from ECMWF System 4 data.

The crops of both basins considered here are strongly rain-fed, so the assumption is made that if a global model is able to predict seasonal rainfall over an area of interest, then the same global model's output can also be used in a statistical forecast system to predict a rain-fed commodity such as crops. A downscaling modelling system to predict seasonal crop yields over the Limpopo (southern Africa) and Oum-er-Rbia (Morocco) river basins was developed. ECMWF System 4 data were transformed from GRIB into the format required by the statistical software package used in the analysis. Ensemble mean data and 3-month averaged sea-level pressure (SLP) and 850 hPa geopotential height data are the predictors considered. ECMWF S4 low-level circulation data for the three-month season prior to the period of harvesting is transformed into normal distributions then post-processed into crop using the model output statistics (MOS). MOS equations are developed by using the principal component regression (PCR;) option of the Climate Predictability Tool (CPT) of the International Research Institute for Climate and Society (IRI; <http://iri.columbia.edu>)

The low-level circulation fields of the ECMWF System 4 (S4) are used as predictors in a principal components regression (PCR) approach to test the predictability of seasonal crop yields over the two basins. The models are tested over a 26-year period to determine their deterministic skill levels, as well as over a 16-year retro-active forecast period to test their probabilistic skill capabilities. The three-month season prior to the period of harvesting is selected based on the assumption that the seasonal averaged low-level circulation during that three-month period is associated with the rainfall over the region of interest and hence related to the production of dry land crops. Limpopo DJF hindcast are used throughout, and for Oum-er-Rbia, both FMA (for coastal and plains) and MJJ (for mountains) hindcasts are used. The hindcast fields used in the MOS equations are restricted over a domain that covers an area between the equator and 45°S and from 20°W to 60°E for the Limpopo downscaling, and from 40°N to 30°S and from 150°E to 20°W for Oum-er-Rbia downscaling

Deterministic skill is determined over a 26-year period for the harvest years of 1983 to 2008. Cross-validation is performed with a large 5-year-out design to minimise the artificial inflation of skill. Retro-active forecasting is applied over the 16-year period from 1993 to 2008 to produce a set of probabilistic downscaled hindcasts. The Relative Operating Characteristic (ROC) was used to test for systematic discrimination and as a verification measure, and the reliability diagram was used determine if the confidence communicated in the hindcasts is appropriate. If the area below ROC curves is ≤ 0.5 , the model discriminates correctly only for



less than half the time. For a maximum ROC score of 1.0, perfect discrimination has been obtained.

The main results for the Limpopo basin are:

- Significant forecast skill was mainly restricted to the Rustenburg agricultural district. Agricultural district yield indices (normalised values)
- Discrimination was achieved, especially for the Rustenburg agricultural district, but the ability to predict for high yields for this district is restricted to lead-times up to two months. useful skill for Rustenburg can be seen for both high and low yields at short lead times.
- Good reliability for the prediction for low yields (a consequence of drought) can be seen for Rustenburg (middle panel), but over-confidence is found in predicting high yields for all three districts.

The main results of the Oum-er-Rbia case study are:

- Skill may be found for the mountains and coastal areas, but very low predictability is seen over the plains of the basin.
- Probabilistic skill suggests potential for making yield predictions over the mountains and over the coastal areas. Poor skill was found over the plains
- Good discrimination was found in mountain areas and for high yields. At a 2-month lead-time, high and low yields are well discriminated for both the coastal and mountain areas, and so we will present a reliability analysis of the forecast system at this lead time only. There was good reliability for predicting low yields over the mountain and coastal areas, but the prediction of high yields has been found to be over-confident

The study carried out presents a baseline that needs to be outscored by such sophisticated approaches. Examples of these approaches include the use of physical crop models that assimilate output from global climate models on temporal and spatial scales reconcilable with their requirements.

4.3.6 Packaging of forecasts for use as early warning information

Seasonal forecasting provides a statistical summary of the weather events occurring in a given time period. The principal aim of seasonal forecasting is to predict the range of values which is most likely to occur during the next season.

Forecast information should include the following:

- a) Onset of rainfall
- b) Seasonal distribution/pattern of rainfall
- c) Streamflow, dam levels etc.
- d) Crop harvests
- e) Fodder/forage availability

The probability of a conditions/range of values being achieved should be easily understood at the application level of the forecast information as well as the implications.

The probabilistic Relative Operating Characteristics (ROC) score calculated using the hit rate (HR) and false alarm rate (FAR) for forecasts is a useful tool for drought detection/early warning. For drought applications the timing of the rainy seasons, amount of precipitation and its inter-annual variability are important

4.4 DROUGHT RESPONSE

An adequate drought response consists on actions that are activated whenever a warning threshold is overcome. Potential actions have two components (**Figure 4-4**Figure 7-1): (1) drought prevention, which concerns those measures aimed at preventing drought causing damage; and (2) drought preparedness, which concerns those measures which enable societies to respond rapidly to drought.

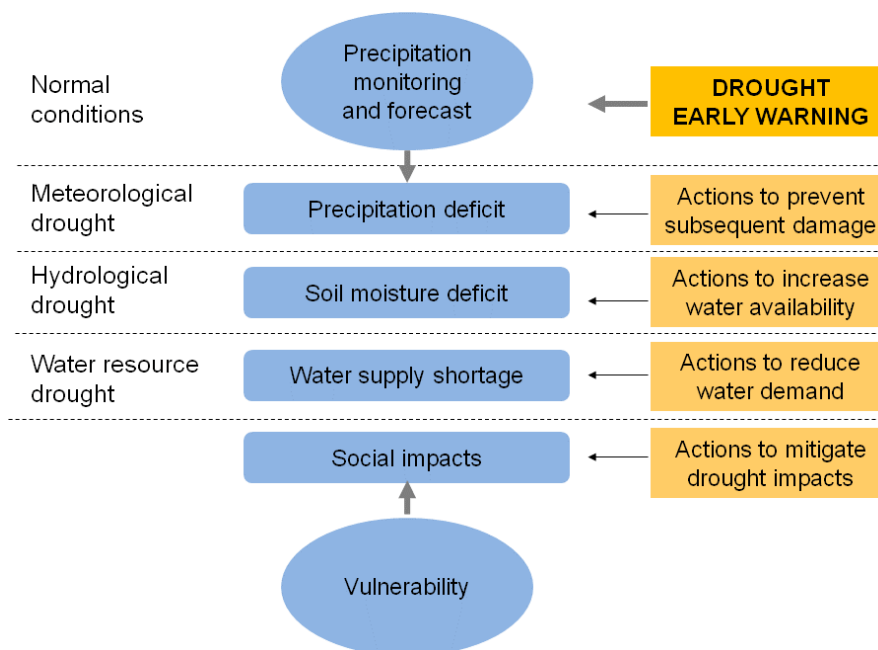


Figure 4-4: Potential actions that may be included in a DEWS



Methods for defining **drought vulnerability** across Africa identified in Work Package 3 (WP3), deliverables D3.1 and D3.2 include the following:

- Thresholds of drought indices defined by comparing time-series of indices with drought impacts. They include the following:
 - ENSO, Precipitation, Percentage of Normal Precipitation, SPI, PDSI,
 - Streamflow, state of reservoirs,
 - SWSI, crop yield
 - State of ecosystems, adaptive capacity, exposure, coping capacity, social response and adaptive capacity
- Drought characteristics captured as duration, frequency, intensity, timing of onset, extend and predictability.

D3.2 identified 28 global publicly available datasets with variables related to drought vulnerability.

4.4.1 Formulation of actions

The development of a drought mitigation plan should be informed by a clear assessment of the drought in terms of onset, deficit and duration. Mitigation actions reduce the impact of the deficit at onset and throughout the drought period. Other mitigation actions such as relief actions deal with the post-drought situation. This the objectives of the drought mitigation plan and should be clearly stated.

Drought mitigation actions may range from increasing the security of water supplies through water storage schemes (such as dams or micro-level water harvesting schemes), increasing the proportion of food production which is irrigated, increasing the efficiency with which available water sources are utilised, introducing or ensuring the retention of crop varieties which are drought-resistant, encouraging the greater use of adaptive strategies by farmers, to diversifying the sources of employment and income in an area into activities which are less vulnerable to the effects of drought.

4.4.2 Prioritisation of actions

Priorities may be established based in on such concerns as feasibility, effectiveness, cost, and equity. In choosing the appropriate actions, it might be helpful to ask some of the following questions:

- What are the cost/benefit ratios for the actions identified?



- Which actions does the general public deem feasible and appropriate?
- Which actions are sensitive to the local environment (i.e., sustainable practices)?
- Are your actions addressing the right combination of causes to adequately reduce the relevant impact?
- Are your actions addressing short-term and long-term solutions?
- Which actions would fairly represent the needs of affected individuals and groups?

A tool to rapidly assess the cost and benefits of mitigation actions should be implemented to help give effect to the vulnerability assessments. Vulnerability assessment seeks to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. At the framework level, drought risk analysis can relate hazard to vulnerability. Low hazard and low vulnerability = no risk, high vulnerability and high hazard=high risk

When a forecast shows societal impacts then the early warning connects to vulnerability assessment. Translation of forecasted variables into a potential economic or societal impacts becomes important. Impacts can be expressed as damages. When the expected value of damages exceeds a given threshold, some management actions/interventions may be required to reduce the risk.

D3.2 focused on the study of drought vulnerability. Patterns of drought vulnerability can be mapped using the following drought-related indicators at a suitable spatial scale: Indicators of adaptive capacity or conversely vulnerability include cultivated area, % of total country area cultivated, Arable land, Area covered by permanent crops, Irrigation potential, Irrigation potential as % of arable land, Population, % Rural Population, % Urban Population, Population Density, % Total economically active population, % Total economically active population in agriculture, Human Development Index, Agriculture Value added to GDP%, access to water % of total population, access to water % population, urban and rural population %, access to sanitation as % of population, urban and rural population %, Number of dams, Total dam capacity, average annual precipitation, renewable water resources total and internal, per capita renewable water resources, agricultural water use % of total, total renewable/natural groundwater, infrastructure vulnerability index, storage as % of annual renewable fresh water resources, storage drought index, vulnerability of the renewable natural capital, vulnerability of the economic capital, vulnerability of civic and human resources, vulnerability of infrastructure and technology, Drought vulnerability index



To ensure that the DEWFORA research brings the state-of-the-art in drought related research to the operational domain and provides viable and effective solutions with direct applicability in Africa the following vulnerability indices were tested in the case studies and the results are applied in early warning protocol in WP5:

- Oum-er- Rbia Basin: Streamflow, crop, yield, rainfall, adaptive capacity, exposure, SPI, NAO, vulnerability
- Niger River Basin: Precipitation, streamflow, reservoir operation, state of ecosystems, adaptive capacity, exposure, Predictive indicator, Coping capacity
- Limpopo River Basin: Precipitation, streamflow, crop, yields, management, rules, institutional, response, adaptive capacity, exposure, social response
- Eastern Nile Basin: Hydrological indicators, adaptive capacity, exposure, SWSI and ENSO, social response

Stakeholders are engaged directly in the evaluation of vulnerability using a guideline developed on this D3.2 (Table 5) to rank vulnerability and D3.2 (Table 6) to evaluate potential impacts and causes of drought (see D6.2L, D6.2OR, D6.2NB, D6.2N)

4.4.3 Drought Response

The most common drought response actions practiced in Africa are as follows (D2.2):

- a) Food aid, drought relief programs,
- b) growing of drought tolerate crops,
- c) saving livestock,
- d) improved water use efficiency and installation of boreholes, wells and small dams

Communities in Africa are engaged in the following activities to be able to survive future droughts and climate change, depending on duration and magnitude of deficit (D2.2):

- a) water harvesting, construction of water infrastructure,
- b) traditional/cultural practices and technologies,
- c) water conservation,
- d) crop monitoring and crop diversification



5 WHAT ARE THE SOCIETAL CAPACITIES AND CHALLENGES?

In this component, the societal capacities and challenges (impediments and weaknesses) that stand against drought preparedness are evaluated. This activity was addressed in DEWFORA in Work Package 2, that reviews the existing capacities in Africa for monitoring, forecasting and early warning of drought at local, regional and continental scales, as well as mitigation practices and adaptation strategies. Following the analysis, recommendations are made as to what specific institutional or organisational changes would be needed to improve the existing preparedness plans.

The current situation in Africa reveals a large number of institutions are involved in *drought monitoring and forecasting systems/ networks/ institutions and projects identified of which global (18), Europe plus the African continent(2), Europe plus Northern Africa(4) , Africa Continental (3), regional (8) and national (104)*

- *At the global level and in USA and Australia there is the Global Drought Monitor, WATCH, the National Drought Mitigation Centre (NDMC), the US Drought Monitor, the North American Drought Monitor (NADM), the Drought Impact Reporter, the Seasonal Drought Outlook, the National Integrated Drought Information System (NIDIS) and the CSIRO*
- *Those covering Europe and Africa Continental include the European Drought Observatory and the EARS Energy and Water Balance Monitoring System (EEWBMS)*
- *Those covering Europe and Northern Africa comprise EEWBMS , XEROCHORE, AQUASTRESS, CIRCE and MEDROPLAN*
- *Those covering the whole continent of Africa include TIGER, the African Water Cycle Coordination Initiative and the Experimental African Drought Monitor*
- *In Africa at regional level, in Tunisia covering the SAHEL- Observatory of Sahara and Sahel (OSS) and the Observatory Network for Long Term Ecological Monitoring Écouter Lire phonétiquement (ROSELT). In Kenya- IGAD, the Climate Prediction and Applications Centre (ICPAC), the USAID Famine Early Warning Systems Network (FEWS NET). In Botswana – the Southern Africa Regional Climate Outlook Forum (SARCOF), the USAID FEWS NET and the SADC Climate Services Centre. In South Africa the USAID FEWS NET. In Burkina Faso the USAID FEWS NET*

Barriers to the use of forecast information noted in **WP2**, include the following:



- a) User difficulties in accessing the forecast and early warning information;
- b) Lack of understanding of the format in which the forecast information is presented;
- c) User difficulties in evaluating and trusting the forecasts;
- d) Failure to interpret the information and convert it into actionable tasks/responses and
- e) Lack of knowledge on how to manage the risks associated with the uncertainty of forecasts.

Forecasts are not frequently used in actual decision making. Practitioners in water resources management, agriculture, health, finance and other key sectors often encounter barriers in utilising the science-based forecasting and early warning information for decision making at the local level. They increasingly worry about drought risks but remain largely at a loss as what to do in the pre-drought period. The potential of globally available drought forecasts and early warning data/information as well as knowledge of mitigation and adaptation measures as “state of the art” remains largely untapped.

The impact of climate change on frequency of occurrence and severity of droughts in Africa was analyzed using a variable-resolution coupled global climate model (CGCM) model, the conformal-cubic atmospheric model (CCAM). It was applied for both seasonal forecasting and the projection of future climate change. The Coordinated Regional Downscaling Experiment (CORDEX) ensemble of high-resolution projections of future climate change over Africa, uses different regional climate models, downscaling the output of the CGCM projections with simulations at about 50 km resolution. However the spatial resolution of CGCMs is inadequate for studying regional impacts of future climate change. Statistical downscaling requires long time-series of observed records of sufficient quality, for the empirical relationships to be established a severe limitation for most of Africa. Reliability of climate change projections can only be verified after several decades but successful replication of hind-cast trends can also increase confidence in forecasts.

The following were the main findings on future climate change projections.

- a) CCAM ensemble-average projected change in annual temperature for 2071-2100 versus 1961-1990 suggests significant change in 75 percentile and 50 percentile temperature may be experienced over most of Africa
- b) CCAM ensemble-average projected change in very hot days for 2071-2100 versus 1961-1990 suggests significant change in 75 percentile and 50 percentile very hot days may be experienced over most of Africa
- c) CCAM ensemble-average projected change in annual rainfall for 2071-2100 versus 1961-1990 suggests significant change in 75 percentile and 50 percentile annual rainfall may be experienced over most of Africa

WP4 investigates advances in early warning capabilities as well as the limitations in the science.

Accurate or reliable drought forecasts and early warning information coupled with timely mitigation measures can reduce the impacts of droughts in Africa and at the same time create conditions for drought adaptation. Recent scientific improvements in meteorological and hydrological forecasting are providing more reliable information for decisions on drought management. However, there is still room for further improvements which require capacities at different levels.

Figure 5-1 illustrates the different elements in a framework to address user requirements for drought monitoring and early warning. The framework recognizes that **users require** different types of information but this has to be usable and timely. This imposes certain conditions on the frequency and reliability of **outputs** from the monitoring and early warning systems. This information is generated through application of models or tools on **input** data, which has to be adequate, accurate and timely. **Resources** required to support this framework include funding, policies, procedures, methods, people, and infrastructure. The focus of the analysis in this document is on the outputs, inputs and resources of the systems in Africa in order to understand the gape that exists between them and with 'state of the art'.

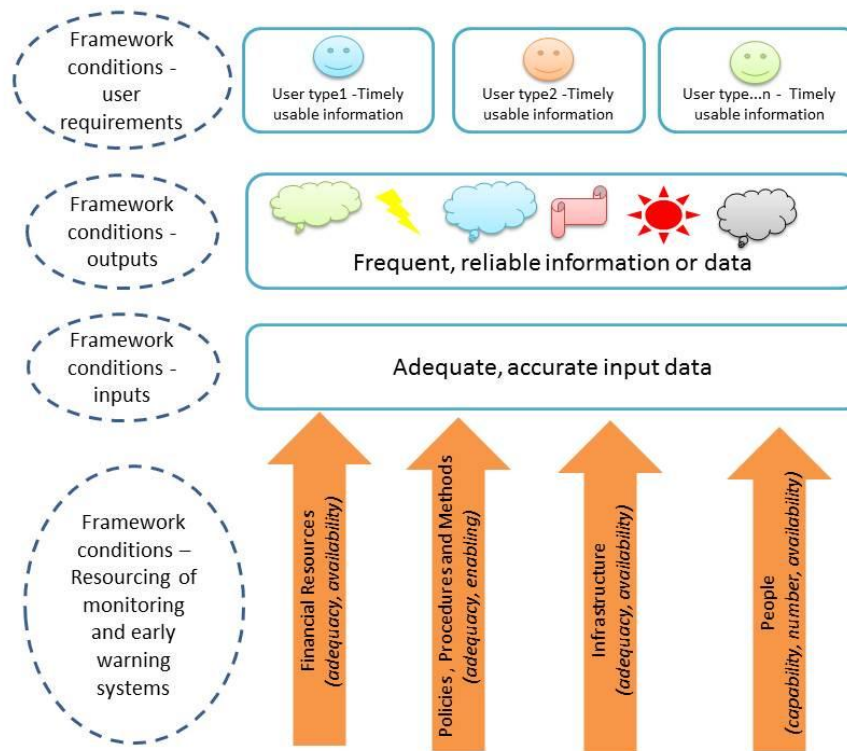


Figure 5-1: Comparative analysis of monitoring and early warning systems – Framework diagram.

This document provides a framework for downscaling of drought warning and mitigation from national to local scale to address the barriers and gaps identified in WP2 and consider the findings in WP3 and WP4.

5.1 CURRENT SOCIETAL CAPACITIES

The method applied for evaluating institutional capacity includes mapping the organizations and institutions relevant to DEWS (defined in WP2) and evaluating the process of DEWS development according to a mental model that includes the analysis of data and forecasting systems available, linkages among relevant institutions, organizations and stakeholders and summary of the proactive and reactive plans and actions.

5.1.1 Data and forecasting systems

In D2.1, an inventory of existing drought monitoring and forecasting systems was made. A total of 138 drought monitoring and forecasting systems, networks, institutions and projects were identified. The 138 are spread as follows: 18 are of global scope, 2 correspond to Europe plus the African continent, 4 cover Europe plus Northern Africa, 3 are centred in Continental Africa, 8 are of regional scope and 104 are of national scope. Table 1 presents a summary of identified systems.



Table 1 Main drought monitoring and forecasting systems in Africa

Scope	Example of drought monitoring systems/projects
Global	Global Drought Monitor WATCH National Drought Mitigation Centre (NDMC) US Drought Monitor North American Drought Monitor (NADM) Drought Impact Reporter Seasonal Drought Outlook National Integrated Drought Information System (NIDIS) CSIRO
Europe and Africa	European Drought Observatory EARS Energy and Water Balance Monitoring System (EEWBMS)
Europe and Northern Africa	EEWBMS XEROCHORE AQUASTRESS CIRCE MEDROPLAN
Africa	TIGER African Water Cycle Coordination Initiative Experimental African Drought Monitor
Regional- Tunisia and Sahel	Observatory of Sahara and Sahel (OSS) Observatory Network for Long Term Ecological Monitoring ROSELT).
Regional- Kenia	IGAD, the Climate Prediction and Applications Centre (ICPAC) USAID Famine Early Warning Systems Network (FEWS NET).
Regional- Tunisia and Sahel	Observatory of Sahara and Sahel (OSS) Observatory Network for Long Term Ecological Monitoring ROSELT).
Regional- Botswana	Southern Africa Regional Climate Outlook Forum (SARCOF) USAID FEWS NET SADC Climate Services Centre.
Regional- South Africa	IGAD, the Climate Prediction and Applications Centre (ICPAC) USAID Famine Early Warning Systems Network (FEWS NET).

From the analysis of existing DEWS in Africa, the following conclusions can be drawn.

Monitoring systems in African countries are inadequate considering the variability of precipitation and flow, sizes of catchments/aquifers and variability of geophysical conditions. In addition, historical data is not readily available to users. There is a decline on the meteorological stations due to high maintenance costs. 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. Locally collected data is also useful for regional, continental and global forecasting and early warning systems, but data sharing is inadequate between government agencies and research institutions. High costs limits application of data in drought monitoring, preparedness, mitigation and response. Rainfall, temperature data and the 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, USGS, WMO, UN etc

The resources managed and the technology applied by drought monitoring and forecasting systems are very diverse. Modelling and local knowledge systems applied to provide drought early warning in Africa include global modelling systems, national modelling systems, local knowledge systems and indices. There is experience in the application of temperature, SPI, NDVI, land use/cover, solar radiation and other indices. NOAA forecasts and model predictions from ECMWF, the UK Met Office and the ECHAM3 dynamical model are being applied supported by radar and rain gauge measurements. There are challenges in simplifying, downscaling and packaging information to address user preferences, the use of language and media accessible to users. Hydrological drought forecasts are generated from models which use historical inflow or statistical methods. These are set up for local conditions. Other information used included consumption requirements for the main water users, rainy versus dry days, vegetation health, groundwater levels and volumes of water stored in reservoirs. Local knowledge systems are used widely as drought predictors. There is limited use of atmospheric forcings, socio-economic parameters related to assessment of drought impact, elevation or soil information.

Institutions are trying to collaborate to combine skills available to improving the quality of the product. Effort has been made on water resources assessment in Africa and as well as hydrological modelling, data acquisition and compatibility for the use with various models. Spatial extent of drought is well documented at national and administrative scales. This is informed by the need to map of drought impacts in terms of food shortage and people affected. Mapping of drought at catchment scale, the unit used in water management is not well documented. Seasonal forecasting tools which utilize atmospheric science may provide more useful information for regional droughts than for catchments the unit used in water management because they are not accurate enough for the requirements at this of scale. At catchment and local scales, local knowledge systems seem to perform better however more studies are required on this systems to create confidence in the scientific community.

In Africa the infrastructure is generally inadequate (equipment, computers, software, etc.) although a few organisations such as the CSIR in South Africa are well equipped. In addition financial resources are very limited. It is very difficult to recover costs for forecasting products as they are generally free to those who want to take them up. The consequence is that forecasting and early warning systems available in Africa are not adequately maintained; recalibration and troubleshooting are inadequate.



The analysis of human resources showed limited availability of skilled scientists, technicians and support staff to operate drought early warning systems. More skilled people are needed in Africa and this can be done through research programmes on analysis and interpretation of information and development of usable products. So far, capacity building efforts have proven inadequate. 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. The following levels not well represented for monitoring and use of information:

- Basin Authority
- Headquarters
- Regional support centres
- River forecast centres
- National centres
- Climate centres
- Workforce/extension officers

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”, which results in unreliable product downscaling to regional and local levels. There is limited climate based monitoring, scientific analysis and research Funding for research programmes especially on water resources assessment, hydrological modelling, water accounting and data compatibility is inadequate.

5.1.2 Institutional analysis

Institutional analysis is important to understand the concept, to identify the institutions and map them to ensure the relevance of subsequent drought management analysis. The analysis aims to provide insights to the following key questions:

- Are all stakeholders included into the network?
- Do the organisations and institutions interact within a formal or an informal network?
- Are there networks to provide communication and hierarchical flows of command?
- What is the degree of influence and dependence of the stakeholders’ decisions on the institutions’ core themes?

Many different institutional arrangements exist for drought mitigation and adaptation in Africa and these are mainly at regional to national and local levels. The effort for effective drought warning and mitigation involves all organizations and institutions related with the



management of water resources. The institutions are classified into policy-level institutions, executive-level institutions, user-level institutions and the NGO's institutions, at national, regional, district and local levels. D2.2 identified the different types (distinguished by role) of institutions involved in drought mitigation. The most common actions being agriculture extension services, food aid, policy, advocacy and water supply. However the most common institutions in the formal institutional frameworks for drought mitigation are agriculture extension services, food aid, policy and funding; advocacy and water supply are excluded.

The most common drought mitigation actions include: food aid and drought relief programs, growing of drought tolerant crops, saving livestock, improved water use efficiency, installation of boreholes, wells and construction of small dams. In some cases, actions are activated by triggers which are typically certain thresholds of drought indices.

The main direct users of drought early warning information in Africa include the following (D2.3):

- Hydrological Services
- Research Agencies
- Catchment Management Agencies/Water Authorities
- Departments of Water – Water Resources Operation and Planning
- Departments of Agriculture – directorates responsible for communicating drought forecasts to users
- Disaster Management Organisations
- Municipalities/District councils – directorates responsible for communicating drought forecasts to users
- UN Agencies
- Large irrigation water users
- NGOs involved in drought monitoring and forecasting
- USAID FEWSNET

In many occasions, agencies mandated to manage water, weather services and agriculture interpret formal/scientific warnings for users. Drought monitoring and early warning information is used for preparing and providing relief, lobbying for relief fund, estimation of relief funds and for carrying out vulnerability assessment. NGOs often take over responsibilities for drought mitigation but they have strong limitations. The sustainability of NGO interventions is not guaranteed. NGOs often cover a very wide range of activities to sustain themselves and they have limited personnel for extended programs. Their activities are specific for a given project and area and funds rely on good will donations. As a result, the NGO approach has engendered a culture of dependency from relief efforts.



There is generally a lack of urgency in responding to drought early warnings where they have been issued. Users generally attribute this to the fact that the warnings do come with information on what actions users should take. At the local level, poverty, lack of education, lack of funds and political influence also have had negative impacts while at the national level delays in decision making have been experienced.

It is evident from this study that early warning on food security to inform emergency food relief is important in Africa. Famine early warning systems and networks across Africa are coordinated by FEWSNET. These networks include regional, national and local vulnerability assessment committees. FEWSNET publishes a monthly bulletin on food security. Remote sensing and ground truthing techniques are applied in generating food security forecasts.

National MET provide weather forecasts as well as seasonal climate outlooks. Unfortunately on drought early warning the application of seasonal and long range climate forecasts for drought early warning still has a limited number of users. Most of the communication involves forecast precipitation versus long term historical precipitation, as an indicator, SPI is not widely applied. Forecasting precision decreases when the spatial focus is narrowed from global, to regional, to national, to local levels.

In contrast to this, indigenous knowledge systems are applied widely. In most cases the lead time for indigenous knowledge systems is very short. They typically detect the onset of drought or whether a drought is being experienced already. However drought early warnings from both formal and local knowledge systems do not provide adequate information on duration, magnitude of drought as well as the spatial extent. Information from formal knowledge system is too coarse for local application. The user response to early warning from local knowledge systems is fine-tuned through historical experiences and in most parts of Africa the history is quite long. As a result warnings and responses find expressions in local language and customs. The forecasting precision of local knowledge system decreases when the spatial focus is increased even at local levels.

The need to link formal systems to local knowledge systems is quite evident from this study coupled with methods which allow learning and adaptation.

The description of models and data that are used to derive the drought early warning information is very weak. This could be attributed to the limited time available for this study which constrained data gathering to small samples for questionnaire surveys and a few interviews. However, the low level of technical and scientific personnel in most of the organisations issuing early warning products suggests limitations in application of methods, tools and data. The scientific knowledge on drought forecasts obtained from atmospheric and



hydrological conditions and potential impacts needs to be considered in drought management plans. This knowledge should be based on monitoring and prediction. The information should be presented to stakeholders as an "integrated monitoring and early warning" product and request their evaluation as an element of adaptation strategies. For example, an ideal integrated monitoring and early warning product for agriculture should incorporate information about climate, soil, water supply, and potential agricultural yields. Ideally, information should be in the public domain and it should be sufficient to gauge the level of risk and make informed decisions about the future

Table 2 shows an evaluation of the institutions strengths and weaknesses for implementing or developing drought preparedness and management plans which include concrete mitigation actions.

Table 2 Summary of the major issues identified in the analysis of institutional arrangements

Topic	Relevant issues
Data and Information	Data networks are inadequate in terms of the density of stations. Worsening trend due to high maintenance costs. Limited availability and high cost of historical data Problematic data quality Current approach to financing data collection is not appropriate. Limited collaboration with international agencies (NASA, WMO, UN, etc)
Institutional Organization	Lack of structures for managing drought at the local level. Responsibilities divided among too many institutions. Lack of coordination and integration amongst institutions. Inadequate infrastructure: forecasting systems, models and software Lack of equipment and technology to generate reliable information
Institutional Performance	No clear drought management policies and drought mitigation plans Reactive drought management actions. Little activity on vulnerability assessment and management Inadequate spatial resolution of drought impact assessment Lack of technical capacity Insufficient human resources and inadequate training Inadequate financial resources. Funds rely on good will donations
User involvement	Many user types involved Public agencies interpret formal/scientific warnings for users Apart from NGO's, the involvement of the private sector is very weak NGO activities are specific for a given project and area Distribution networks are non-existent, they rely on government and other NGOs to implement programs

5.2 FINANCIAL AND LEGAL CAPACITIES

A financial and legal framework is required to:

- d) Manage uncertainties associated with forecast information when applied at the local level
- e) Mobilize finances to support implementation of mitigation measures



- f) Manage the legal consequences of lack of action or transfer of risks

It includes mechanisms to raise and distribute funds or materials (or food) and the laws and by-laws to enforce certain human behaviour in order to obtain the desired outcomes or prevent undesirable ones.

5.3 INSTITUTIONAL CAPACITIES

A clear institutional framework is important for assigning responsibilities for tasks to be undertaken. The institutional framework includes policies and guidelines that make it possible for people to intervene in an organised manner. An institutional framework is required to undertake the following tasks:

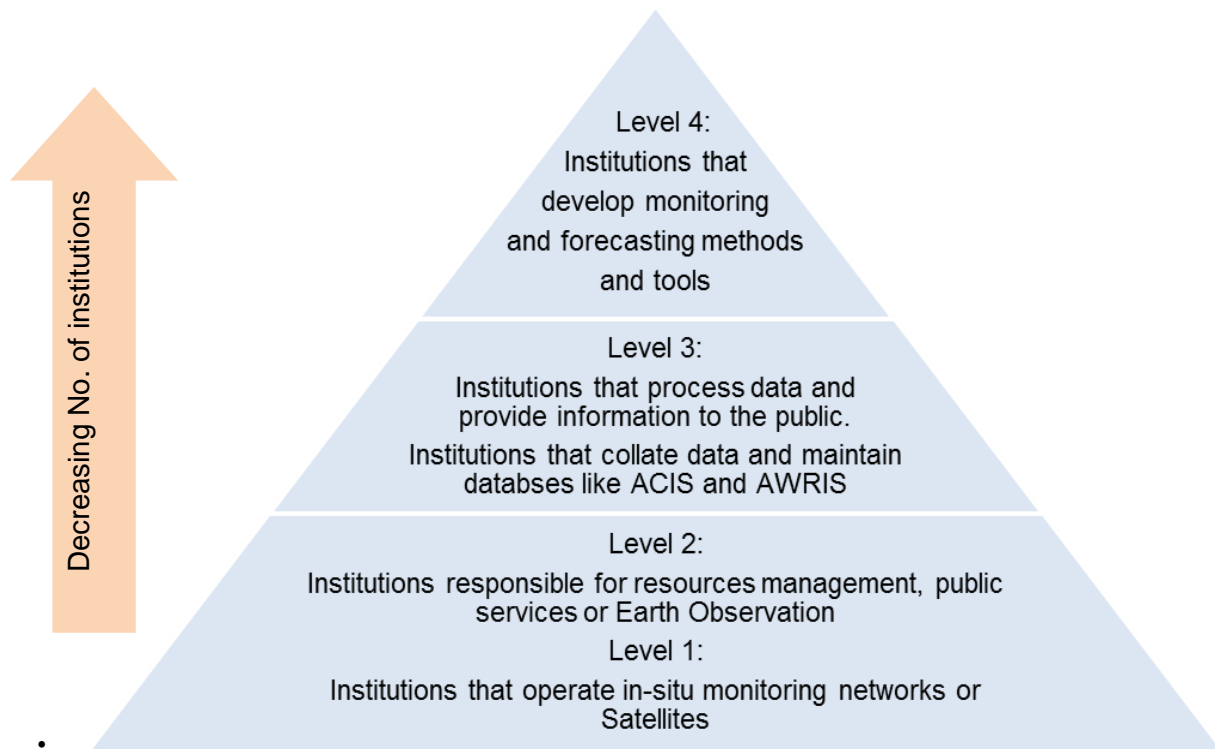
- f) Collect monitoring information from the local level and provide it to the forecasters at national/global level;
- g) To obtain user requirements;
- h) To downscale and package forecast and early warning information to suit user requirements;
- i) To monitor performance of forecast and mitigation information, obtain user feedback, and recommend updating of the information;
- j) Facilitate the flow of information between the national and local level

A focus on vulnerability may prove to be very effective since it includes the evaluation of the capacity to anticipate and compensate the adverse effects of drought.

5.4 WHERE ARE IMPROVEMENTS REQUIRED?

In D.2.4, an extensive analysis of gaps in existing drought monitoring and forecasting systems in Africa was carried out. The analysis demonstrates that there is a disconnection between the institutional responsibilities for drought monitoring, forecasting and early warning in Africa and the end user requirements. There is also a disconnection between available resources and responsibilities. “State of the art” suggests that improved distribution of responsibilities as follows:

- Level 1: Institutions involved in monitoring but some also provide forecast information;
- Level 2: Institutions responsible for resources management, public services or Earth observation;
- Level 3: Institutions that process data and provide information to the public. Institutions that collate data and maintain databases also fall into this category;
- Level 4: Institutions that develop monitoring and forecasting methods and tools.



The institutional framework allows data to be passed to different institutions for value addition. A framework to address user requirements for drought monitoring and early warning was developed in D2.4. This framework recognizes that **users require** different types of information but this has to be usable and timely. This imposes certain conditions on the frequency and reliability of **outputs** from the monitoring and early warning systems. This information is generated through application of models or tools on **input** data, which has to be adequate, accurate and timely. **Resources** required to support this framework include funding, policies, procedures, methods, people and infrastructure. The analysis is done by focusing on the **outputs, inputs and resources** in order to understand the gap that exists between different systems in Africa and with ‘state of the art’ systems. The main requirements of users of drought monitoring and forecasting systems in Africa based on review of available literature and limited interviews can be summarised as follows:

- Seasonal forecasts which means forecasts with a lead time of 2 to 5 months depending on length of season;
- Reliable data for each system, level or resource, which should be preferably from a single source;
- Evidence of success rate of forecasts based on history to improve confidence of users should be included in forecasts;
- Predictions should be available at local scale (forecasts should zoom to areas which users can relate to);



- Users have experience with occurrence of rainfall, therefore the spatial scale for predictions should consider variability of rainfall;
- Easy to understand information (communicate risks of forecast clearly to enable users incorporate this information into their own risk management frameworks);
- Drought forecasts should include recommendations on how users should respond;
- A tool that translates forecasts into information on the availability of water in rivers and dams.

In Africa, the number of users of “state of the art” outputs is very small. The main challenges for drought forecasting and early warning systems in Africa are as follows:

- Early warning information where it exists is delivered on an occasion basis. End users do not get information in suitable format at the time they need it. Systems for disseminating or delivery or exchange of information in a timely manner are not well developed or inexistent, limiting their usefulness for decision support;
- Early warning information is often too technical, limiting its use by decision makers and farmers. End users are not involved in product verification. There are no customer’s/users networks to ensure product verification and service feedback;
- Early warning information is often unreliable on the seasonal timescale and lacks specificity, reducing their usefulness for agriculture and other sectors;
- Drought impact assessment methodologies are not standardized or widely available, which limits the formulation of regionally appropriate mitigation and response programs;
- Drought indices are generally inadequate even for detecting the onset and end of drought;
- Integration of information into government structures is poor and focuses on emergency response rather than long-term planning;
- Users are not aware of the range of early warning products that they can use.

To improve drought mitigation and adaptation, attention is required on:

- Training and public awareness campaigns especially 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



- Integration of scientific and local knowledge based drought forecasting and monitoring systems
- Effective transfer of information to policy-and decision-makers
- Performance evaluation and institution capacitation at regional, national and local levels
- Improvement of link between relief efforts and development programmes

The existing institutional arrangements for drought mitigation in Africa offer following opportunities:

- The framework for mobilization of government agencies exists and substantial resources can be brought together
- Institutional structures for implementation of drought mitigation and adaptation interventions exist
- The need for strategies to mitigate drought is generally appreciated and the need for drought early warning systems is also appreciated
- Communities are engaged in activities to be able to survive future droughts and climate change, depending on duration and magnitude of deficit. This is being done through changes in processes, practices, and structures to moderate potential impacts of future drought and
- More institutions identified are not on the formal framework. This can be addressed in the short term to improve integration.

6 HOW CAN SCIENCE BE TRANSLATED INTO POLICY?

A science-based approach for preparedness and early warning is the key for later operational management and determines the success of the overall DEWS. The following aspects need to be considered:

1. Definition of the actions to reduce social vulnerability (permanent measures).
2. Identification of the alert mechanisms/signals based on thresholds of indicators that allow raking of risk levels in agriculture, ecosystems and water supply systems

We propose a science-based approach to identify alert mechanisms. For example, when probability of drought damage exceeds a minimum threshold, mitigation actions are taken and implemented (Figure 6-1).

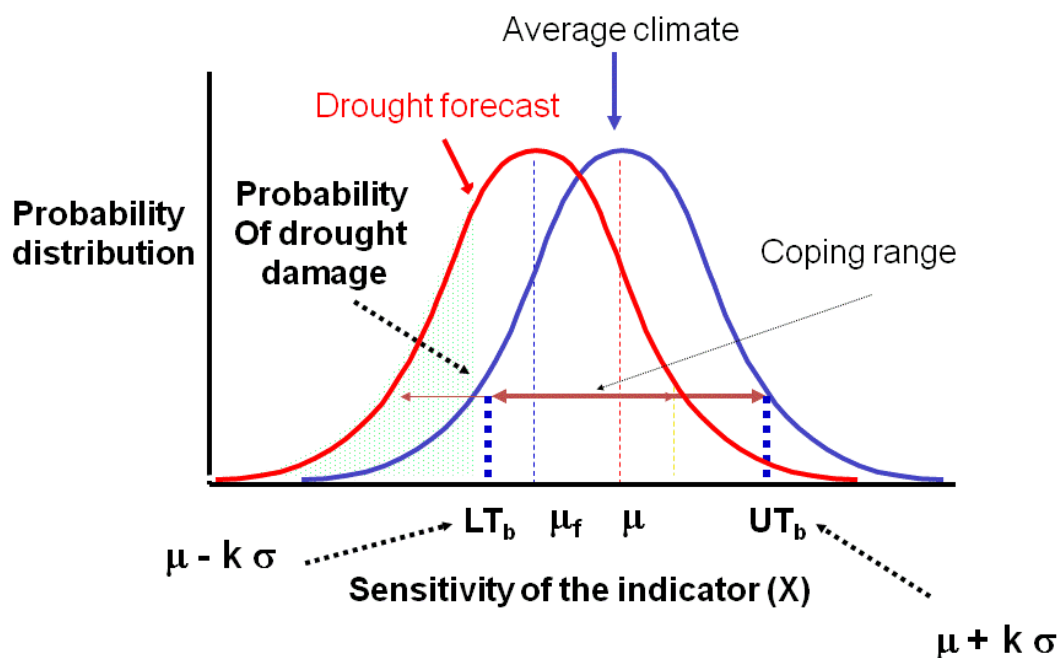


Figure 6-1 Example for definitions of thresholds to trigger drought alert

Communicating probabilities is a difficult task. From the academic point of view, the probability distribution functions (see example in Figure 6-2). Nevertheless, this is not effective for communication with some stakeholders groups and the work in WP2 and WP6 need to provide insights on how to communicate probabilities in the various levels of stakeholders involved in DEWS. The historical experiences of drought in D2.2 provide a good benchmark for communicating impacts of future droughts. An effective way of

presenting the drought early warning is by a combination of maps, graphs, diagrams, tables and animations.

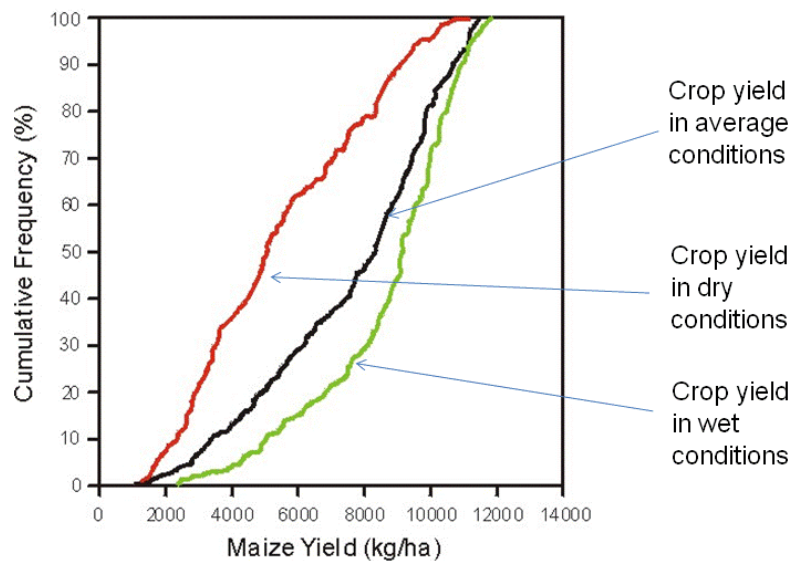


Figure 6-2 Example of probability distribution functions of crop damage during drought

The challenge is to ensure that complex models are transparent and provide insight to users. This will have to be analysed in the case studies.

Policy briefs developed in WP8 **contain information on target groups, suggestions on most suitable moment to communicate with them, form of brief (document, presentation and one liners).**

6.1 POLICY BRIEFS IN THE EUROPEAN CONTEXT

The main messages include out of scientific research which needs to be taken up by policy makers such as:

- Improvement/strengthening of the skill of forecasting products, illustrated with examples or with analogies
- Transfer of knowledge from Europe to Africa and from Africa to Europe
- More funding for research on certain emerging/promising topics for example forecasting products

The following are the main **targets**:

1. European Commission; DG RTD, DG ENV, DG DEVCO and DG CLIMA
2. European parliament (eventually STOA)
3. UN; WMO in particular



6.2 POLICY BRIEFS IN THE AFRICAN CONTEXT

The main messages include out of scientific research which needs to be taken up by policy makers such as:

- Institutional networks should be improved
- Data networks should be improved
- Early warning should be improved as well as mitigation actions
- Cooperation within Africa is essential
- Understanding and mapping of vulnerability/risks is indispensable to a better preparedness

The following are the main **targets**:

- At continental level the main targets are; AU, AMCOW, AMCEN
- At the regional level at the level of technical groups the main targets are; RBO's, Economic zones (SADC, ECOWAS, IGAD, etc), NELSAP (Nile Equatorial Lakes Subsidiary Action Program)
- National level; government ministries, department and agencies
- NGOs



7 HOW CAN SOCIETY BENEFIT FROM IMPROVED FORECASTS?

The provision of improved information to potentially affected groups is the final step for effective DEWS; this includes the following aspects:

1. Define the actions to be taken upon drought, establishing priorities during water scarcity situations.
2. Evaluate the process to implement the actions, the political process, and the links between drought, water and development policies.
3. Define of the process to ensure communication.
4. Review process

7.1 PRIORITISING POTENTIAL ACTIONS

Potential actions have two components (Figure 7-1): (1) drought prevention, which concerns those measures aimed at preventing drought causing damage; and (2) drought preparedness, which concerns those measures which enable societies to respond rapidly to drought.

Drought mitigation actions may range from increasing the security of water supplies through water storage schemes (such as dams or micro-level water harvesting schemes), increasing the proportion of food production which is irrigated, increasing the efficiency with which available water sources are utilised, introducing or ensuring the retention of crop varieties which are drought-resistant, encouraging the greater use of adaptive strategies by farmers, to diversifying the sources of employment and income in an area into activities which are less vulnerable to the effects of drought. Reference can be made to the range of actions identified from historical drought given in D2.2.

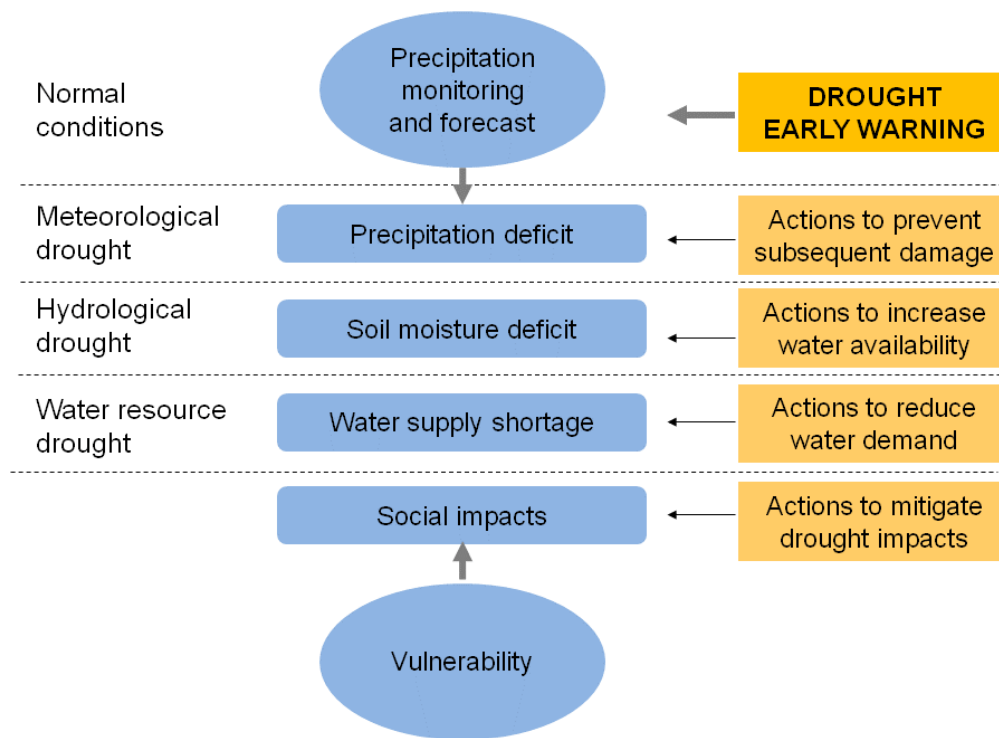


Figure 7-1 Potential actions that may be included in a DEWS

Priorities may be established based in on such concerns as feasibility, effectiveness, cost, and equity. In choosing the appropriate actions, it might be helpful to ask some of the following questions:

1. What are the cost/benefit ratios for the actions identified?
2. Which actions does the general public deem feasible and appropriate?
3. Which actions are sensitive to the local environment (i.e., sustainable practices)?
4. Are your actions addressing the right combination of causes to adequately reduce the relevant impact?
5. Are your actions addressing short-term and long-term solutions?
6. Which actions would fairly represent the needs of affected individuals and groups?

A tool to rapidly assess the cost and benefits of mitigation actions should be implemented to help give effect to the vulnerability assessments.



7.2 PROCESS TO IMPLEMENT THE ACTIONS

The following aspects may be considered on the implementation process:

1. Assess the availability of skilled human resources needed for drought preparedness planning
2. Educate policy makers and the public on the need for improved drought preparedness as an integral part of water resources management
3. Support creation of regional drought preparedness networks to enhance regional capacity in sharing lessons learned
4. Enhance regional and international collaboration
5. Recognize the role of WMO, ISDR, NMHSs, and regional/national institutions in drought early warning and preparedness

The implementation of drought mitigation actions should be embedded within existing institutions.

7.3 COMMUNICATION

Effective communication and public participation will increase the quality and acceptance of the DEWS, since this: (a) ensures acceptance of or trust in the science that feeds into the planning; and (b) provides essential information and insights about drought preparedness, since the relevant wisdom is not limited to scientific specialists and public officials.

Participatory methods, such as interactive approaches, or structured dialogues, are recommended.

7.4 REVIEW PROCESS

Developing an effective framework for drought forecast, early warning which leads to timely implementation of mitigation actions is not an end-to-end process, but needs to be revised and reviewed in light of new science and evolving institutions and societies as well as drought.

8 CONCLUSIONS

The framework for drought forecasting, early warning and mitigation in Africa proposed here will assist in establishing policy priorities based on scientific evidence that also strengthen existing institutions. Overall, a science-based approach is a useful guideline, but a number of challenges are recognized. Risk-based approaches to preparing for drought are focused on



acquiring accurate probabilistic information about the events themselves. When this is not possible, the strategy fails. In contrast, understanding and reducing vulnerability does not demand accurate predictions of the incidence of extreme drought. Nevertheless, it may be politically difficult to justify drought vulnerability reduction on economic grounds.



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ANNEX A

1 EVIDENCE FROM CASE STUDIES

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1.1 INTRODUCTION

This Annex provides a summary of the main findings from the work carried out in WP2, WP3 and WP4 and consolidated on the case study basins in WP6 in order to provide the context to apply the framework and guidelines for effective drought early warning and response in Africa.

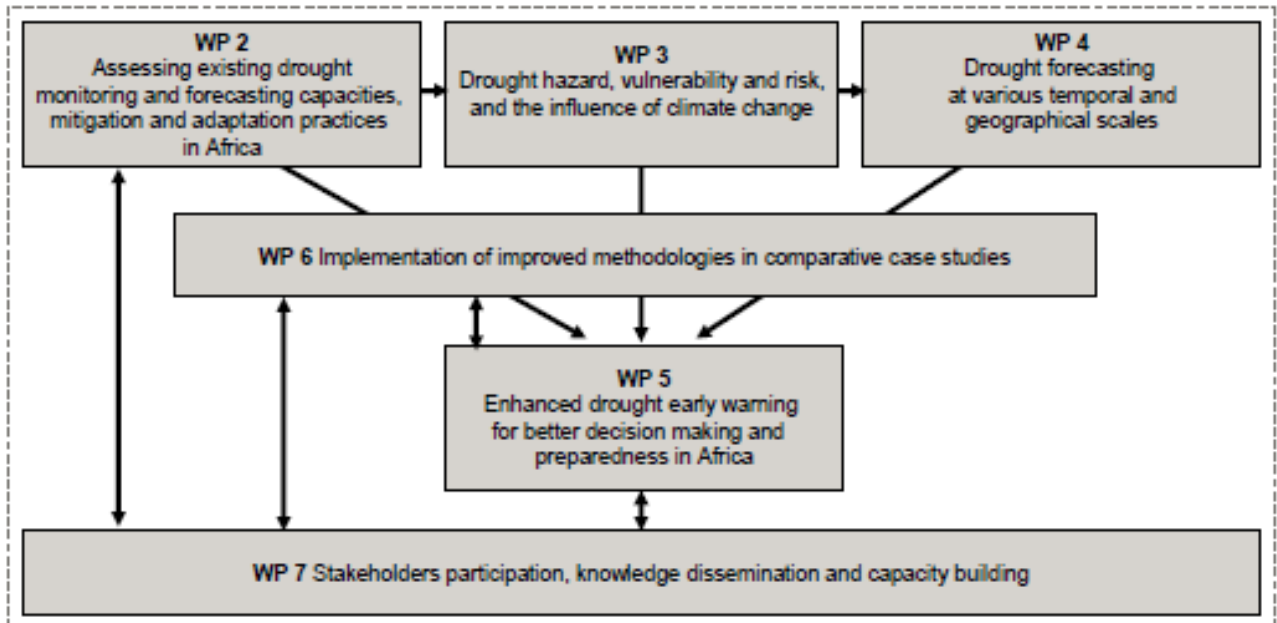


Figure 1-1 Contribution of WP2, 3, 4 and 6 to the framework for and guidelines for effective drought early warning and response in Africa

2 CURRENT DROUGHT MONITORING AND FORECASTING CAPACITIES (WP2)

2.1 DROUGHT MONITORING AND FORECASTING SYSTEMS IN AFRICA

The DEWFORA teams identified 138 drought monitoring and forecasting systems/ networks/ institutions and projects identified, 55 factsheets and 54 detailed descriptions completed. The 138 are spread as follows: global (18), Europe plus the African continent (2), Europe plus Northern Africa(4) , Africa Continental (3), regional (8) and national (104).

At the global level and in USA and Australia there is the Global Drought Monitor, WATCH, the National Drought Mitigation Centre (NDMC), the US Drought Monitor, the North American Drought Monitor (NADM), the Drought Impact Reporter, the Seasonal Drought Outlook, the National Integrated Drought Information System (NIDIS) and the CSIRO.



Those monitoring systems covering Europe and Africa Continental include the European Drought Observatory and the EARS Energy and Water Balance Monitoring System (EEWBMS). Those covering Europe and Northern Africa comprise EEWBMS, XEROCHORE, AQUASTRESS, CIRCE and MEDROPLAN. Those covering the whole continent of Africa include TIGER, the African Water Cycle Coordination Initiative and the Experimental African Drought Monitor.

In Africa at regional level, in Tunisia covering the SAHEL- Observatory of Sahara and Sahel (OSS) and the Observatory Network for Long Term Ecological Monitoring Écouter Lire phonétiquement (ROSELT). In Kenya- IGAD, the Climate Prediction and Applications Centre (ICPAC), the USAID Famine Early Warning Systems Network (FEWS NET). In Botswana – the Southern Africa Regional Climate Outlook Forum (SARCOF), the USAID FEWS NET and the SADC Climate Services Centre. In South Africa the USAID FEWS NET. In Burkina Faso the USAID FEWS NET.

In Africa at national level there are Departments of Meteorological Services/Weather Services , Hydrological Services, National Research Agencies, River Basin Forecasting Agencies, Catchment Management Agencies/Water Authorities, Department of Water – Water Resources Operation and Planning, Departments of Agriculture – directorates responsible for communicating drought forecasts to users, Remote Sensing Organisations, Disaster Management Organisations, Municipalities/District councils – directorates responsible for communicating drought forecasts to users, UN Agencies ,NGOs involved in drought monitoring and forecasting, USAID FEWSNET.

Modelling and local knowledge systems applied to provide drought early warning in Africa include global modelling systems, national modelling systems, local knowledge systems and indices. In Italy the Windisp is applied, Netherlands - RIBASIM - River basin modelling, Europe - Agri4cast - Agricultural modelling, USA-Cropsyst - Agricultural modelling; SWAT ; IHACRES - River system modelling; HEC-HMS - River system modelling, NOAA operational environmental satellites, AVHRR-derived indices, Spain- AquaTool DMA, Algeria -Agro-ecological Information system (SGIAR), Morocco- SMAPS - Drought Early warning system for Maghreb region; RAN, SPI,PDSI; Deviation analysis, decile analysis, surface water supply index; Spatial assessment of drought hazard, drought vulnerability assessment and mapping, Decision support system for agriculture (SAADA); Algeria, Morocco, Tunisia- SPI, RA (Precipitation deviation/normal); actual water stress, VCI, TCI; SWSI, SWI; South Africa - Long- lead forecasts, Decile rainfall, Water Satisfaction Index (WSI), NOAA NDVI, SPI, ZA Model, SPATSIM - River basin information system and modelling, Water Resources Yield Model (WRYM), Water Resources Planning Model (WRPM), PUTU Veld Production,



Hydrological Drought Assessment Model (HDAM) - Drought operating rules and forecast trajectories, Flow deviation, Agricultural drought threshold, Southern Africa - Veld/Forest Production, Insect Production

2.2 INSTITUTIONAL FRAMEWORKS

The experience of drought in Africa dates back many centuries but this study identified specific drought years from around 1920s from readily available literature. Hit count of drought reported somewhere for 1921/22 to 1950/51, up 10 successive seasons; 1951/52 to 1980/81-up to 10 successive seasons, 1981/82 to 2008/09 - up to 7 successive seasons (Limpopo River Basin and Maghreb Region only).

Most common drought mitigation actions include food aid and drought relief programs, growing of drought tolerate crops, saving livestock, improved water use efficiency, installation of boreholes, wells and construction of small dams.

Many different institutional arrangements exist for drought mitigation and adaptation in Africa and these are mainly at regional to national and local levels. Some frameworks are activated by triggers which are typically certain thresholds of drought indices.

The main drought mitigations actions carried out are agriculture extension services, food aid, policy formulation and provision of direction, advocacy and water supply.

Existing institutional frameworks for drought mitigation mostly involve institutions which provide agriculture extension services, food aid, policy direction and funding. Water Infrastructure Development and Management, Forecasting and Early Warning are missing.

Four different type of drought adaptation actions take place namely water infrastructure development, water infrastructure development, agriculture extension services and policy.

Four different types (distinguished by role) of institutions are involved in drought adaptation namely water infrastructure development, water infrastructure management, agriculture extension services and policy.

2.3 EXPERIENCES IN EARLY WARNING

In general, local knowledge systems are used widely as drought predictors. Users of drought early warnings include communities, government departments (main ones are water, agriculture, fisheries and disaster management), Local government, Research agencies, NGOs, UN agencies international cooperating partners. Agencies mandated to manage water, weather services and agriculture interpret formal/scientific warnings for users.



Drought monitoring and early warning information is used for preparing and providing relief, lobbying for relief fund, estimation of relief funds and for carrying out vulnerability assessment.

Spatial extent of drought is well documented at national and administrative scales. This is informed by the need to map of drought impacts in terms of food shortage and people affected. Mapping of drought at catchment scale, the unit used in water management is not well documented.

Seasonal forecasting tools which utilize atmospheric science may provide more useful information for regional droughts than for catchments the unit used in water management because they are not accurate enough for the requirements at this of scale.

At catchment and local scales, local knowledge systems seem to perform better however more studies are required on this systems to create confidence in the scientific community.

2.4 GAPS IN THE MONITORING AND FORECASTING SYSTEMS

There is experience in the application of temperature, SPI, NDVI, land use/cover, solar radiation and other indices. Other information used included consumption requirements for the main water users, rainy versus dry days, vegetation health, groundwater levels and volumes of water stored in reservoirs. There is limited use of atmospheric forcings, socio-economic parameters related to assessment of drought impact, elevation, soil information, satellite data including AVHRR, MODIS, GRACE, SRTM, AATSR and routing networks.

The main gaps arising from the current situation included:

- Limited skills scientists, technicians and support staff is a reality in many cases. At the same time, the capacity building efforts are inadequate.
- 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.
- Data sharing is inadequate between government agencies and research institutions.
- High costs limits application of data in drought monitoring, preparedness, mitigation and response. Rainfall, temperature data and the 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 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”, which results in unreliable products downs-calling to regional and local levels.
- Locally collected data is also useful for regional, continental and global forecasting and early warning systems. The current approach to financing data collection is not appropriate. There is limited collaboration with agencies such as NASA, NOAA, USGS, WMO, UN etc.
- Funding for research programmes especially on water resources assessment, hydrological modelling, 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. The following levels not well represented for monitoring and use of information: Basin Authority, Headquarters, Regional support centres, River forecast centres, National centres, Climate centres, and Workforce/extension officers.

2.5 GAPS IN THE INSTITUTIONAL STRUCTURE

The organizational structures in Africa are characterized by:

- LACK OF A DEPARTMENT THAT DEALS SPECIFICALLY WITH DROUGHT related issues and lack of structures for managing drought at the local level. Responsibilities divided among too many institutions with very little capacity. 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. Inadequate infrastructure including drought forecasting systems, advanced models and software and lack of equipment and technology to generate usable/credibility of information. There is no clear drought management policies and drought mitigation plans; Poor support for uptake of science at policy level. Finally, there is inadequate financial resources , lack of technical capacity, insufficient human resources and inadequate training and



- NGOs OFTEN TAKE OVER RESPONSIBILITIES FOR DROUGHT MITIGATION but they have the following limitations. The activities are project area is specific and funds rely on good will donations. NGOs often cover a very wide range of activities to sustain themselves and they have limited personnel for extended programs. The sustainability of NGO interventions is not guaranteed. The distribution networks and non-existent, they rely on government and other NGOs to implement programs. There is inadequate spatial resolution of drought impact assessment and sampling/selection methodologies are generally weak and finally, the NGO approach has engendered a culture of dependency from relief efforts.
- THE EXISTING INSTITUTIONAL ARRANGEMENTS FOR DROUGHT MITIGATION IN AFRICA OFFER FOLLOWING OPPORTUNITIES: (a) The framework for mobilization of government agencies exists and substantial resources can be brought together, (b) Institutional structures for implementation of drought mitigation and adaptation interventions exist, (c) The need for strategies to mitigate drought is generally appreciated and the need for drought early warning systems is also appreciated, (d) Communities are engaged in activities to be able to survive future droughts and climate change, depending on duration and magnitude of deficit. This is being done through changes in processes, practices, and structures to moderate potential impacts of future drought and (e) More institutions identified are not on the formal framework. This can be addressed in the short term to improve integration.
- TO IMPROVE DROUGHT MITIGATION AND ADAPTATION, attention is required on: (a) Training and public awareness campaigns especially in situations where the country is approaching a drought season, (b) Participation of stakeholders and water users, (c) Spatial resolution of early warning systems and updating intervals e.g. seasonal climate outlooks and monthly updates, (d) Integrating scientific and local knowledge based drought forecasting and monitoring systems, (f) Effective transfer of information to policy-and decision-makers, (g) Performance evaluation and capacitation the institutions at regional, national and local levels, and (h) Improve link between relief efforts and development programmes.

3 DROUGHT VULNERABILITY (WP3)

3.1 CONCEPTUAL FRAMEWORK

The methods for defining drought vulnerability across Africa on the DEWFORA study include the following:



Most common indicators of drought hazard are Percentage of Normal Precipitation, SPI, PDSI and, SWSI. Specific criterion is required for regional and local drought analysis. The period of analysis depends on the characteristics of the system and the processes involved.

- Thresholds of indices are defined by comparing time-series of indices with drought impacts.
- Drought characterisation requires information on duration, frequency, intensity, timing of onset, extend and predictability.
- On evaluating vulnerability consider the following steps: (i) define hazard (meteorological or hydrological etc); (ii) define the impacts in agriculture, water, ecosystems, health, etc; (iii) define exposure (number of people affected); and (iv) define coping capacity or adaptive capacity).

The applicability of these definitions is tested in the case studies and the results are applied in early warning protocol in WP5. Indicators suggested for Case study areas:

- Oum-er- Rbia Basin: Streamflow, crop, yield, rainfall, adaptive capacity, exposure
- Niger River Basin: Precipitation, streamflow, reservoir operation, state of ecosystems, adaptive capacity, exposure
- Limpopo River Basin: Precipitation, streamflow, crop, yields, management, rules, institutional, response, adaptive capacity, exposure
- Eastern Nile Basin: Hydrological indicators, adaptive capacity, exposure
- Pan- African Level Extreme forecast indices, precipitation, SPI

3.2 MAPPING VULNERABILITY

Vulnerability assessment seeks to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors.

At the framework level, drought risk analysis can relate hazard to vulnerability. Low hazard and low vulnerability = no risk, high vulnerability and high hazard=high risk

When a forecast shows societal impacts then the early warning connects to vulnerability assessment. Translation of forecasted variables into potential economic or societal impacts becomes important. Impacts can be expressed as damages



The "coping range" of society may be described as the maximum perturbation from mean conditions that can be accepted without significant damages.

When the expected value of damages exceeds a given threshold, some management actions/interventions may be required to reduce the risk.

Patterns of drought vulnerability can be mapped using the following drought-related indicators at a suitable spatial scale.

Indicators of adaptive capacity or conversely vulnerability include cultivated area, % of total country area cultivated, Arable land, Area covered by permanent crops, Irrigation potential, Irrigation potential as % of arable land, Population, % Rural Population, % Urban Population, Population Density, % Total economically active population, % Total economically active population in agriculture, Human Development Index, Agriculture Value added to GDP%, access to water % of total population, access to water % population, urban and rural population %, access to sanitation as % of population, urban and rural population %, Number of dams, Total dam capacity, average annual precipitation, renewable water resources total and internal, per capita renewable water resources, agricultural water use % of total, total renewable/natural groundwater, infrastructure vulnerability index, storage as % of annual renewable fresh water resources, storage drought index, vulnerability of the renewable natural capital, vulnerability of the economic capital, vulnerability of civic and human resources, vulnerability of infrastructure and technology.

3.2.1 Drought vulnerability index

- There are 28 global publicly available datasets with variables related to drought vulnerability.
- To ensure that the DEWFORA research brings the state-of-the-art in drought related research to the operational domain and provides viable and effective solutions with direct applicability in Africa the following vulnerability indices are tested in the case studies and the results are applied in early warning protocol in WP5:
- Oum-er- Rbia Basin: Streamflow, crop, yield, rainfall, adaptive capacity, exposure, SPI, NAO? vulnerability
- Niger River Basin: Precipitation, streamflow, reservoir operation, state of ecosystems, adaptive capacity, exposure, Predictive indicator? Coping capacity



- Limpopo River Basin: Precipitation, streamflow, crop, yields, management, rules, institutional, response, adaptive capacity, exposure, social response
- Eastern Nile Basin: Hydrological indicators, adaptive capacity, exposure, SWSI and ENSO, social response
- It is proposed that representative stakeholders be engaged in evaluating vulnerability within the DEWFORA case studies. The stakeholders in each case study may be engaged directly in the evaluation of vulnerability using a guideline developed on this deliverable D3.2 (Table 5) to rank vulnerability and Table 6 to evaluate potential impacts and causes of drought.

3.3 DOWN SCALLING GLOBAL MODELS

3.3.1 Current achievements include:

Coupled global climate models (CGCMs) have become the primary tools for the projection of future climate change. Dynamic and statistical downscaling may be used to obtain more detailed projections of future climate change for an area.

CGCM projections, such as those described in the Assessment Report Four (AR4) of the IPCC, are currently the main source of information regarding plausible scenarios of future climate change over southern Africa.

The Coordinated Regional Downscaling Experiment (CORDEX) is generating a large ensemble of high-resolution projections of future climate change over Africa, using different regional climate models from different institutions, downscaling the output of the CGCM projections contributing to the Coupled Model Inter-comparison Project (CMIP5) and AR5. Simulations are performed at a resolution of about 50 km.

Spatial resolution of CGCMs are of inadequate for studying regional impacts of future climate change. Application of hydrological models over the Niger, Limpopo and Eastern Nile river basins require resolutions as high as 8 km to provide adequate descriptions of the intensity and spatial resolution of rainfall events for the forcing of hydrological models. dynamic regional climate models (RCMs) applied over the area of interest include limited-area models, which have fixed lateral boundaries, and variable-resolution global models.

With statistical down-scaling present-day relationships between large-scale circulation patterns and near-surface variables such as rainfall remain stationary in time which may not be valid, under conditions of enhanced anthropogenic forcing. Statistical downscaling



requires long time-series of observed records of sufficient quality, for the empirical relationships to be established a severe limitation for most of Africa.

Although reliability of climate change projections can only be verified after several decades confidence in the projections can be enhanced through the application and verification of climate models at verifiable time scales for example inter-annual changes can be verified by projections at seasonal time-scales. Successful replication of hind-cast trends can also increase confidence in forecasts.

Traditional limited-area RCMs cannot be used as global models, whilst the majority of global models cannot be applied as regional climate models (except for the computationally expensive case of high-resolution global runs). Variable-resolution global models provide the best framework for performing simulations across a range of spatial and time scales.

On DEWFORA a variable-resolution global atmospheric model, the conformal-cubic atmospheric model (CCAM), is applied for both seasonal forecasting and the projection of future climate change.

Downscaling of CGCMs using CCAM Multiple nudging: CCAM first integrated globally at 2 degree resolution, followed by 0.5 degree resolution simulations over Africa domain. CRUTEMP3v linear temperature trend 1961-2010 - Strong warming has occurred over the western and central parts of Southern Africa. Warming more moderate along the coastal areas. Simulated annual temperature anomalies (1961 to 2100) relative to the 1961-1990 climatological average suggest more pronounced trends towards warming after 2013.

CCAM ens-ave projected change in annual temperature for 2071-2100 vs 1961-1990 suggests significant change in 75 percentile and 50 percentile temperature may be experienced over most of Africa.

CCAM ens-ave projected change in very hot days for 2071-2100 vs 1961-1990 suggests significant change in 75 percentile and 50 percentile very hot days may be experienced over most of Africa

CCAM ens-ave projected change in annual rainfall for 2071-2100 vs 1961-1990 suggests significant change in 75 percentile and 50 percentile annual rainfall may be experienced over most of Africa

Malherbe et al. (2012) projected change in tropical cyclone and tropical low frequencies over the South Western Indian Ocean and southern Africa, for 2071-2100 relative to 1961-1990 suggests weakening cyclones? General drying is projected over north-eastern South Africa



and the Limpopo River Basin during summer and autumn partially the result of the northward displacement of tropical low and cyclone tracks over the southwestern Indian Ocean.

Rainfall anomalies over the Ethiopian Highlands vs SST anomalies in Nino 3.4 over the Pacific show a negative correlation.

3.3.2 The investigation in progress include:

Impact of enhanced anthropogenic forcing on the occurrence of meteorological and hydrological drought over the Niger and Blue Nile river basins – very high-resolution simulations (8 km in the horizontal).

Impact of ENSO on rainfall over the Eastern Nile basin, under both present-day and future forcing.

4 FORECASTING (WP4)

4.1 METEOROLOGICAL DROUGHT

- DATASETS FOR ESTIMATION OF DROUGHT INDICATORS. The meteorological data includes: (i) the European Centre for Medium/Range Weather Forecasts (ECMWF) ERA-Interim (ERA-I) reanalysis and long-range weather forecasts, and (ii) the Council for Scientific and Industrial Research (CSIR) in South Africa conformal-cubic atmospheric model (CCAM) seasonal forecasting system.
- DATASETS AVAILABLE. The following datasets are available from ECMWF from ERA-I global atmospheric reanalysis and long range forecasts:
 - Atmosphere global forecasts. Forecast to ten days from 00 and 12 UTC at 16 km resolution and 91 levels (in 2011/12: ~137 levels).
 - Ocean wave forecasts. Global forecast to ten days from 00 and 12 UTC at 28 km resolution.
 - European waters 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 (to day 32 on Thursdays at 00 UTC, in 2011: also on Mondays + 46d on the 15th of each month); 32 km resolution up to day 10, then 65 km, and 62 vertical levels (in 2011: ~95 levels); 12 UTC with persisted SST up to day 15, 00 UTC with persisted SST up to day 10 and then coupled ocean model (in 2011 coupled both at 00 and 12 UTC);



Coupled ocean has horizontally varying resolution ($\frac{1}{3}$ to 1°), 29 vertical levels (in 2011 new ocean model NEMO and NEMOVAR DA); Coupled wave model.

- Seasonal forecasts: Atmosphere-ocean coupled model. 41-member global forecasts to seven months (in 2011: System 4); atmosphere: 120 km resolution, 62 levels (80km, 91 levels); ocean: horizontally-varying resolution ($\frac{1}{3}^\circ$ to 1°), 29 levels (NEMO and NEMOVAR); re-forecast suite: 11 members x 25 years (15 members x 30 years, 1981-2005).
- Reanalysis: Since January 1979 to present (near real time update); Atmosphere: 80 km horizontal resolution with 62 vertical levels; 6 hourly analysis, 12 hour 4D-Var assimilation; 10 days forecasts (at 00 and 12 UTC).
- Two ensemble forecasting systems are currently **operational** at ECMWF: Variable resolution ensemble prediction system (VarEPS) produces (i) weather forecasts out to 32 days and (ii) seasonal forecasting produces forecasts out to 7 months.
- MEDIUM-RANGE. The time scale for medium-RANGE (up to day 15) and monthly (up to 7months) weather forecasting is too short for variations in the ocean significantly to affect the atmospheric circulation, hence it is essentially an atmospheric initial state problem, the ECMWF medium-range weather forecasting system is based on atmospheric-only integrations. SSTs are persisted.
- SEASONAL FORECASTING are less problematic because of the long predictability of the oceanic circulation (of the order of several months) and by the fact that the variability in tropical SSTs has a significant global impact on the atmospheric circulation. Since the oceanic circulation is a major source of predictability in the seasonal scale, the ECMWF seasonal forecasting system is based on coupled ocean-atmosphere integrations. Seasonal forecasting is also an initial value problem, but with much of the information contained in the initial state of the ocean.
- MONTHLY FORECASTING SYSTEM: the system includes the following: The monthly forecasting system comprised the medium-range VAREPS in ocean-atmospheric coupled mode after day 10. The real-time VarEPS/monthly forecasting system is a 51-member ensemble of 32-day integrations. The first 10 days are performed at 0.28x0.28 degrees resolution forced by persisted SST anomalies (updated every 24 hours). After 10 days the model is coupled to the ocean model and has a resolution of 0.56x0.56 degrees. Drift is removed from the model solution during the post-processing. The probability distribution function (pdf) of the model climatology is



evaluated to detect any significant difference between the ensemble distribution of the real-time forecast and climatology. The climatology is a 5-member ensemble of 32-day VarEPS/monthly integrations, starting on the same day and month as the real time forecast for each of the past 18 years.

- SEASONAL FORECASTING SYSTEM: The system includes the following. The principal aim of seasonal forecasting is to predict the range of values which is most likely to occur during the next season. The atmospheric component of the coupled model is the ECMWF IFS (Integrated Forecast System) model version 31r1. The horizontal resolution used for seasonal forecasts is 1.125x1.125 degrees. The seasonal forecasts consist of a 41 member ensemble. The ensemble is constructed by combining the 5-member ensemble ocean analysis with SST perturbations and the activation of stochastic physics. The forecasts run for 7 months. A set of re-forecasts (otherwise known as hindcasts or back integrations or just referred as climatology) are made starting on the 1st of every month for the years 1981-2005. Use the ECMWF data finder <http://www.ecmwf.int/products/data/archive/finder.html> to specify data requests (without using the order function). Data are delivered in the GRIB format, use GRIB API3 to read, write and manipulate that data format under an Apache Licence.
- The conformal-cubic atmospheric model (CCAM) is currently being run operationally as seasonal forecasting system at the Council for Scientific and Industrial Research (CSIR) in South Africa.
- CCAM is configured to generate a 28-year set of hindcasts as a result of forcing the CCAM with predicted, as opposed to persisted, SST anomalies
- The ECHAM4.5-MOM3-DC2 (12 ensemble members; 74.25°S to 65.25°N) and ECHAM4.5-GML-CFSSST (12 ensemble members; 46°S to 46°N) forecasts data sets are available from January 1982 to present. The model data are obtained from the data library of the International Research Institute for Climate and Society. The observed SST data sets used are the 1°x1° resolution data of NOAA's OI.v2, and the 2°x2° resolution data of NOAA's NCDL ERSST version3b. A statistical model (canonical correlation analysis – CCA) which uses the most recent 3-month mean antecedent global ERSST field as predictor and the OI.v2 global SST as predicted from the two CGCMs. The three models produce a 28-year set of retro-active SST forecasts from 1982/83 to 2009/10 for lead-times up to 6 months. The retro-active forecasts average the three global forecasts to produce an equal weights set of multi-



model forecasts. The same procedure is followed to produce forecasts operationally every month. The operational forecasts and verification statistics are presented on the website of the South African Risk and Vulnerability Atlas (<http://rava.qsens.net/>)

- The following drought indexes can be estimated using forecasts and reanalysis data: SPI, PDSI, Standardized Evapotranspiration index, Standardized runoff index , Soil Moisture index
- ERAI and GPCP precipitation datasets show good agreement in the mid-latitudes and poor correlation over the tropical regions in terms of precipitation estimates and spatial extent

4.2 SKILL OF THE FORECASTING SYSTEM

The application of seasonal prediction using coupled dynamical models to drought forecasts is still in the early stages.

Observation-based precipitation datasets include: i) the Global Precipitation Climatology Centre version 4 (GPCCv4); ii) the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP); iii) the Global Precipitation Climatology Project versions 2.1 and 2.2 (GPCPv2.1/2) and; GPCC is only based in rain-gauges, while GPCP and CMAP blend data from a variety of satellites and gauges.

- Quality and availability of precipitation datasets for drought monitoring in Africa;
- ERAI precipitation has limitations for drought applications, especially over the tropical rainforest, because of drifts in the model climate. However, in the other regions, it compares reasonable well with the remaining datasets and has the potential to be used as a monitoring tool because of its near real time update (in contrast with the other datasets). Furthermore, a robust evaluation of seasonal forecasts is dependent on the verification dataset. Since there is no clear information on which dataset is more reliable, the seasonal forecasts of precipitation were verified against GPCPv2.2.
- The ERAI configuration has a spectral T255 horizontal resolution (about $0.7^{\circ} \times 0.7^{\circ}$ in the grid-point space) with 60 model levels. For comparison purposes the previous ECWMF ERA40 reanalysis (Uppala et al. 2005) ($1.125^{\circ} \times 1.125^{\circ}$) was also included. A k-mean clustering algorithm to GPCPv2.1 in order to identify regions with homogeneous precipitation climatologies. The GPCP and CMAP datasets are available in a $2.5^{\circ} \times 2.5^{\circ}$ latitude/longitude grid while the other datasets have higher



resolutions. There is a tendency of the reanalysis products (both ERAI and ERA40) to overestimate precipitation in the tropical rainforests.

- Four global precipitation datasets over Africa and ECMWF reanalysis highlight the uncertainty associated with accurate estimates of precipitation for verifying purposes.
- There is a high uncertainty of precipitation estimates over Africa. A robust evaluation of seasonal forecasts is strongly dependent on the verification dataset.

CURRENT SKILL OF SEASONAL FORECASTS of precipitation in Africa has the following characteristics:

- multi-model ensemble (MME) forecasts do not consistently outperform any particular model. S4 is the only viable seasonal forecast system, produced by ECMWF, which can be used in DEWFORA.
- It is not possible to predict the daily weather variations at a specific location months in advance because of the chaotic nature of the atmospheric circulation. It is not even possible to predict exactly the average weather, such as the average temperature for a given month. Seasonal forecasts provide a range of possible climate changes that are likely to occur in the season ahead. Seasonal forecast systems were taken from the EUROpean Seasonal to Inter-annual Prediction (EUROSIP) archive at ECMWF.
- EUROSIP consists of 3 seasonal forecasting systems from ECMWF, Met Office and Météo-France (see Vitart et al.(2007) for further details) namely S3, ECMWF S3-(11 ensemble members, hindcast 1981-2010, 1.125x 1.125 degrees, ECMWF S4-(15 ensemble members, hindcast 1981-2010, 0.7x0.7 degrees), and Météo-France MF-- (11 ensemble members, hindcast 1981-2010, 2.8x2.8 degrees), UK MET Office System 3-(15 ensemble members, hindcast 1987-2008, 2.5x3.78 degrees), Multi-model MM-(44 ensemble members, hindcast 1987-2008),
- Skill score calculation the reference forecast is taken from GPCPv2.2 as a random sample of different years to produce a climatological forecast with the same ensemble size has the system that is verified.
- The multi-model composite (MM) created by combining forecasts from several different models tends to follow the best performing system in terms of the anomaly correlation coefficient (ACC) and the continuous rank probability skill score (CRPSS).



- Forecasts perform better during El Nino and La Nina season than during neutral years.

A case study of the integration of monitoring and forecasting for the recent 2010-11 drought in the Horn of Africa. This includes the following characteristics: The 2010-11 drought in the Horn of Africa resulted from a precipitation deficit in both the Oct-Dec 2010 and Mar-May 2011 rainy seasons, and this was captured by ERAI. Soil moisture anomalies of ERAI also indentified the onset of the drought condition early in Oct 2010 with a persistent drought still present in Sep 2011. The precipitation deficit in Oct-Dec 2010 was associated with a strong La Niña event. The ECMWF seasonal forecasts of NINO3.4 predicted the La Niña event from June 2010 onwards, and also a dry precipitation anomaly for the region from July 2010 onwards. On the other hand, the seasonal forecasts for the Mar-May 2011 season did not predict the anomaly in advance, except for the forecasts in March 2011.

4.3 POTENTIAL IMPROVEMENTS TO EARLY WARNING SYSTEMS

- DATA. Drought monitoring relies on near real time observation of surface variables such as precipitation. Observations can either be derived through the merging of ground observations and remote sensing information or by using re-analysis tools. In-situ observations and suitable forecasting models are required for most of Africa. ERA Interim (ERA-Interim) is the latest global atmospheric reanalysis covers the period from 1 January 1979 onwards (79x79km), and continues to be extended forward in near-real time <http://www.ecmwf.int/research/era>. CAMSOP1 is a merged dataset produced by the 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). CAMSOP1 merged dataset is available from January 1979 (2.5x2.5 degrees) at the CPC ftp site (ftp://ftp.cpc.ncep.noaa.gov/precip/data-req/cams_opi_v0208). Global Precipitation Climatology Project (GPCP) version 2.2 monthly precipitation is available since Jan 1979 to Dec 2010 on a 2.5x2.5 degrees grid. Is GPCP is discontinued?
- METHODS. Integrated monitoring and forecasting system based SPI which uses multiple globally available precipitation products (ERA-Interim and CAMSOP1) and the ECMWF Seasonal Forecasting System 4. The ERA-Interim reanalysis is produced with a sequential data assimilation scheme, advancing forward in time using 12-hourly analysis cycles. In each cycle, available observations are combined with prior information from a forecast model to estimate the evolving state of the global atmosphere and its underlying surface. The basic upper-air atmospheric fields



(temperature, wind, humidity, ozone, surface pressure) are computed, followed by separate analyses of near-surface parameters (2m-temperature and 2m-humidity), soil moisture and soil temperature, snow, and ocean waves. The analyses are then used to initialise a short-range model forecast, which provides the prior state estimates needed for the next analysis cycle. ERAI archive http://data-portal.ecmwf.int/data/d/interim_full_daily. 3-month SPI is associated with short- and medium-term moisture conditions associated with seasonal estimations of precipitation. However, a relatively normal 3-month period (or even wet) can occur during a long drought spell. 6-month SPI is associated with medium-term precipitation anomalies and is usually associated with anomalous stream flows and reservoir levels. 12-month SPI reflects long-term precipitation patterns, that are associated with changes to large reservoirs and groundwater. Drought monitoring in Africa with ERAI is mainly possible outside the ITCZ. To be useful, near-real time monitoring tools have to be carefully selected depending on region. It would be best to use real rain gauge observations.

- SEASONAL FORECASTS. Seasonal forecasting provides a statistical summary of the weather events occurring in a given time period. The principal aim of seasonal forecasting is to predict the range of values which is most likely to occur during the next season. The probabilistic Relative Operating Characteristics (ROC) score calculated using the hit rate (HR) and false alarm rate (FAR) for forecasts is a useful tool for drought detection/early warning. Most of the precipitation over the African continent is controlled by the south to north and back displacement of the Inter Tropical Convergency Zone (ITCZ), the intensity of the low level Tropical Easterly Jet (TEJ) and the flow disturbances in the high level African Easterly Jet (AEJ). Rainfall field over West Africa is characterised by a zone of maximum precipitation that migrates north and south throughout the course of the year (Figure 2). This zone lies to the south of the ITCZ. The variance spectra for rainfall in the LP shows the same peaks found in the Southern Oscillation. Rainfall tends to be organized into mesoscale convective systems. For drought applications the timing of the rainy seasons, amount of precipitation and its interannual variability are important. In figures 5 and 6 the critical part of the graph is the period October to April, begin the graph in September/October to assist in the visual interpretation.(OR and LP).
- RESULTS FROM MERGING MONITORING AND SEASONAL FORECASTS. Precipitation forecasts include:



- Seasonal forecasting in the South and North West of Africa shows good agreement for all data sets, while there is a low agreement in Central Africa (between the +/- 20° parallels).
- Seasonal forecasting in the Blue Nile, Limpopo and Upper Niger shows a higher reliability and skill in comparison with the Congo and Oum er-rbia
- ECMWF seasonal forecasts (System 4) which became available in November 2011 has predictive skill which is higher than using climatology for most regions. The seasonal forecast generates 51 ensemble members in real-time, with 30 years (1981-2010, 15 ensemble members) of back integrations (hind-casts). The lead time is 7 months, including the month of issue..
- In the BN ERAI shows a significant overestimation and CAMSOPI is in good agreement with GPCP annual cycle of precipitation.
- S4 forecasts overestimate precipitation in both BN and NG basins in the first forecast month with a reduction of the peak rainfall with lead time, showing the impact of model drift.
- In the CG basin, ERAI, CAMSOPI and S4 show an early peak rainfall in March (GPCP in April) and a latter peak in November (GPCP in October). ERAI generally overestimates precipitation in CG, while S4 overestimates its amplitude. From the mean annual cycle analysis, CG basins appear as the most problematic with timing errors in the rainy season, and amplitude problems in S4
- In the LP and OR basins all datasets show a reasonable agreement, with an underestimation of the rainy season in OR, and S4 has a reduced drift on both basins.
- In the BN and NG, the ERAI overestimation of precipitation is also reflected in higher inter-annual variability, while in the CG and LP there is a good agreement between ERAI, CAMSOPI and GPCP. The underestimation of precipitation during winter in OR by all datasets is also associated with lower inter-annual variability. The changes in variability with lead time in S4 are smaller than what was found for the mean annual cycle of precipitation.
- In the BN and NG the temporal correlation of both ERAI and CAMSOPI compared with GPCP decays with increasing SPI time-scale. In all basins, except OR, GPCP



has lower decay time scales and higher variance of white noise while ERAI has the higher time scales and lower white noise variance.

- In the NG, both ERAI and CAMSOPI show an opposite trend to GPCP, with a wet period until 2000 and severe and long term drought in the last decade.
- S4 precipitation forecasts in terms of the anomaly correlation coefficient (ACC) for the ensemble mean in the BN, LP and NG basins have skill up to 3 months lead time for the rainy seasons, while in the CG and OR basins S4 does not have skill.
- S4 outperforms the climatological forecasts (CLM) in the basins where the original seasonal forecasts of precipitation have skill (Figure 15 lower panel). Namely BN, LP and NG. In CG and OR, S4 has a similar skill to CLM.
- SPI FORECASTS, include:
 - There is good agreement between the GPCP derived SPI at time-scales higher than 5/6 months, for all calendar months except July, when compared with river discharge anomalies.
 - SPI derived from ERAI and CAMSOPI compared with stream-flow shows much lower or no-existent the correlations. This reflects the poor intra-seasonal to inter-annual variability of precipitation of the ERAI and CAMSOPI datasets in the NG region
 - Taking moderate to severe droughts with an SPI below -0.8, for the SPI-6 the ROC of CLM is close to 0.5 (no information), while with S4 the ROC is higher close to 0.7 in the BN, LP and NG, 0.6 in CG and 0.54 in OR. For the SPI-12 the ROC of CLM is always above 0.5, since the climatological forecast inherits 6 months of monitoring. In this case, it is difficult to beat the climate forecast, but S4 outperforms CLM in the BN, LP and NG basins (as documented before).
 - There is a significant drop in the ACC, especially in the BN, CG and NG basins, CAMSOPI has problems in representing the intra-seasonal to inter-annual variability of precipitation. These problems are present during the monitoring periods and are extended to the forecast period. The quality of monitoring products is very important as they control the skill of the SPI forecasts for accumulation time scales.
 - Seasonal forecasts of the 1991/92 drought in the LP basin with different initial forecast dates starting August 1991 to July 1992, comparing the SPI-12 from GPCP



(verification), CAMSOPI (monitoring) and the S4 and CLM forecast show that skill improves around Nov –Dec for and CLM performs better from Dec onwards.

- The system 4 seasonal forecast has predictive skill which is higher than using climatology for most regions (is this conclusion true?)
- In regions where no reliable near real-time data is available it is better to use just the first month of the season to predict droughts

4.4 HYDROLOGICAL MODELS AVAILABLE

- SELECTION OF A SUITABLE HYDROLOGICAL MODEL, or a combination of models, for a given objective (e.g. drought forecasting in Africa) should be carried out by assessing various models using a set of criteria
- Global Land Surface Models (GLSMs) describe the vertical exchange of heat and water
- Global Hydrological Models (GHMs describe water resources and lateral transfer of water
- EU-WATCH1 project compared the simulation results of six GLSMs and five GHMs. Runs for a baseline of 30 years and for two contrasting forecasted scenarios. The models do not succeed in representing the water balance components in arid and semi-arid basins where there was the largest coefficient of variation (CV) of the global evaporation and runoff
- 5 GLSMs: (i) Variable Infiltration Capacity (VIC), (ii) Minimal Advanced Treatments of Surface Interaction and Runoff (MATSIRO), (iii) Land Dynamics Model (LaD), (iv) ORCHIDEE and (v) Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land (HTESSEL);
- The VIC model runs at a daily time step and is a gridded model with a spatial resolution from 2x 2 degrees up to 1/16 x 1/16degrees but generally applied at a 0.5 x 0.5degrees resolution in the global scale, and it allows for subdivision of the grid cells into a number of elevation bands permitting sub-grid variability in both precipitation and temperature. The model has been applied for identifying regional-scale droughts and associated severity, aerial and temporal extent under historic and projected future climate in Illinois and Indiana, USA. A real time drought monitoring and forecasting system for the Canadian Prairies, Lin (2010) uses the VIC model to



simulate daily soil moisture values starting from 1 January 1950 and is continually running through present with a forecast lead time up to 35 days.

- MATSIRO runs at a daily time step and has a spatial resolution from a fraction of a degree to several degrees latitude by longitude but is generally applied at a 1 x 1 degree resolution when applied globally. The forcing data includes wind velocity, temperature, humidity, pressure, incoming radiation and precipitation in a 6 hourly time step. It uses a simplified TOPMODEL to calculate runoff...where has this model been applied?
- LaD is a large-scale land continental water and energy balances model which may be run either in stand-alone mode or coupled to an atmospheric model. It is generally applied at a 1° x 1degrees resolution grid globally (but it can be applied at smaller resolutions). The energy, soil water, and snowpack equations are solved in an hourly time step and the groundwater equation in a daily time step. LaD was calibrated on nine basins in the north-eastern United States and the Niger River basin in the Sahel region.
- ORCHIDEE solves both the energy balance (on a 1x 1 degrees grid boxes, which is the scale of the forcing used) and the hydrological balance (on a smaller scale) in a time step of 30 min. River flows are computed through basins defined at a 0.5 x 0.5 degree scale. In the semi-humid basins, ORCHIDEE overestimates river discharges by 20-50%, in intermediate basins it underestimates it by 30-60% and semi-arid basins ORCHIDEE overestimates river discharges.. ...where was this model applied?
- HTESSEL has a flexible spatial resolution, depending on the input resolution, and it has been applied globally with a resolution of 0.5°. The model runs with a time step of one hour forced with sub-daily (6 hourly or less) near surface meteorology and surface fluxes. HTESSEL is part of the integrated forecast system at ECMWF with operational applications ranging from the short-range to monthly and seasonal weather forecasts. ...where has this model been applied?
- 11 GHMs: (i) WaterGAP, (ii) PCR-GLOBWB (iii) Macro-scale-Probability-Distributed Moisture Model (Mac-PDM), (iv) Water Balance Model (WBM), (v) Lund-Postdam-Jena model (LPJ), (vi) Soil and Water Assessment tool (SWAT), (vii) SWIM, (viii) HBV (ix) Global Water Availability Assessment method (GWAVA) (x) WASMOD-M and (xi) LISFLOOD



- WaterGAP comprises two main components: a Global Hydrology Model and a Global Water Use Model. It has a spatial resolution of 0.5 x 0.5 degrees and covers the global land area. Calculations are performed with a temporal resolution of one day for which synthetic daily values are generated. WGHM has been tuned for 724 drainage basins worldwide, but resulting discharges were overestimated in some basins. These are often located in arid and semiarid areas. WaterGAP demonstrated a reasonable performance in simulating timing and magnitude of average monthly and low flow values in Europe
- PCR-GLOBWB is a grid-based model of global terrestrial hydrology. It is essentially a leaky bucket type of model applied on a cell-by-cell basis. The model calculates for each grid cell (0.5 x 0.5 degrees) for a daily time step. PCRGLOBWB was used to simulate the discharge with a GCM ensemble mean as forcing data. The resulting discharges were compared with the Global Runoff Data Center (GRDC) discharge data.
- Mac-PDM is usually run at 0.5 x 0.5 degrees spatial resolution, but it has been run at resolutions ranging from 10 x10 min to 2 x 2 degrees. It extends the basin-scale PDM (Probability Distributed Moisture Model) and can be forced with daily or monthly input data
- The WBM simulates grid cell (0.5 x 0.5 degrees) level hydrology associated with long-term climate. The model is deterministic and employs a monthly time step. The WBM is insensitive to precipitation in arid regions and it performs most poorly in extremely dry regions where rapid rain events may have the ability to produce substantial runoff.
- LPJ is a dynamic global vegetation model that simulates the coupled terrestrial carbon and water cycle. The simulations are driven by gridded monthly fields (in general a 0.5x0.5 degrees resolution). Results compare favourably with WBM, Macro-PDM and WaterGAP. Overestimations occur in semi-arid and arid regions, particularly in northern Africa, parts of South America and India. LPJ as well as the three hydrological models overestimate year round runoff in Africa.
- SWAT is a continuous time model and operates at a daily time step but the output can be aggregated and printed at a daily, monthly, or annual time scale. The modelled area can be divided into multiple sub-basins. It has been applied for the whole Africa with monthly resolution, and calibrated and validated it at 207 discharge stations across the continent.



- SWIM is a GIS-based tool for hydrological and water quality modelling in mesoscale watersheds (from 100 to 10,000 km²) which was based on two previously developed tools: SWAT and MATSALU. The model operates on a daily time step.
- HBV is a conceptual hydrological model extensively used in operational hydrological forecasting and water balance studies. The model has been applied in a wide range of scales without modification of its structure. Climatic inputs are on a daily time step, and daily or monthly estimates of potential evaporation. Basins are separated into a number of sub-basins. The HBV was developed for humid temperate conditions, it has also been used successfully in semi-arid and arid countries such as Australia, Iran and Zimbabwe with modifications to include interception which is important for semi-arid basins.
- GWAVA typically operates on 0.5 x 0.5 or 0.1 x 0.1 degree grid and is driven by monthly climate data. Model outputs include simulated monthly flows and a cell-by-cell comparison of water availability. It has been applied to Eastern and Southern Africa, West Africa, the Caspian Sea basin, South America, and the Ganges-Brahmaputra basin, and is currently being applied to Europe. On the PROMISE project, GWAVA was set for the West African region, including 22 countries and a wide range of hydrological regimes and climates. A reasonable degree of calibration against observed flows was attained.
- WASMOD-M model is a distributed version of the monthly catchment model WASMOD and is driven by time series of monthly climatic data on a 0.5 x 0.5 degrees grid. It generally runs on a monthly or annual time step, and there is a daily version of WASMOD- M.
- LISFLOOD is a GIS-based hydrological rainfall-runoff-routing model (implemented in the PCRaster Environmental Modelling language, wrapped in a Python based interface) which is capable of simulating the hydrological processes that occur in a catchment. LISFLOOD is grid-based, and applications so far have employed grid cells of as small as 100 metres for medium sized catchments, up to 5000 metres for modelling the whole of Europe.
- ASSESSMENT OF MODELS, include:
- Evapotranspiration, soil moisture changes, groundwater flow and surface water-groundwater interactions including wetlands are important for most catchments in



Africa. The existing models are dominated by different processes and therefore show significant differences in their water-balance components and response to events.

- Differences in results suggest the need to use multiple hydrological models
- In Africa there are many regions with a lack of good precipitation observations, and this is a limiting factor to application of data intensive models..
- MODEL SELECTION QUALITATIVE CRITERIA using available literature.
- Represented processes and fluxes: Interception , Evaporation, Snow, Soil , Groundwater, Runoff, Reservoirs, Lakes, Routing, Water use, Energy balance and Calibration parameters
- Model applicability to African climatic conditions and physiographic settings: Applicability of the model in semi-arid regions
- Data requirements and resolution of the model (spatial and temporal resolution) Meteorological, Spatial Temporary. A fixed grid size and fixed basin sizes can limit model applicability. Model should be scalable
- Capability of the model to be downscaled to a river basin scale
- Operational model for drought early warning system at large scales
- Open source model is preferred
- Models should be continuous in time i.e. not event models
- Models should be well documented
- More rigor is required on assessment of models on status of documentation on models, available data vs data requirements, ability to provide useful output for specific hydrological drought conditions and specific characteristics of focus areas, development status of model, open source vs proprietary software
- PCR-GLOBWB, GWAVA, HTESSSEL, LISFLOOD and SWAT show higher potential and suitability for hydrological drought forecasting in Africa



4.5 STATISTICAL ANALYSIS OF NATURAL CLIMATIC VARIABILITY AND HYDROLOGICAL PARAMETERS

4.5.1 Data sources

- Runoff - Global Runoff Data Centre (GRDC, <http://www.bafg.de/GRDC>), ARA-SUL - Mozambique and South Africa - the Department of Water Affairs (<http://www.dwaf.gov.za/Hydrology/>).
- What are the flow station names for priorities 1, 2 and 3 and the attitude and longitude attributes?
- Catchment boundaries and rivers - HydroSHEDS data set (<http://hydrosheds.cr.usgs.gov/>).
- Countries - Global Administrative Areas database version 2.0 (GADM, <http://www.gadm.org/>) and the CIA World Data Bank II (<http://www.evl.uic.edu/pape/data/WDB/>).
- ERAI sea surface temperature (ERAI –SST) and HADSST2 sea surface temperature anomaly data sets
- Southern Oscillation Index (SOI), ENSO indexes (ERSST), ENSO indexes (OISST), Darwin sea level pressure (SLP), Tahiti SLP, North Atlantic Oscillation (NAO), Oceanic Nino Index (ONI) - Climate Prediction Center of NOAA <http://www.cpc.ncep.noaa.gov/>
- Indian Ocean Dipole Mode Index (DMI),- Based on NOAA OISST Ver.2 - <http://www.jamstec.go.jp/frcgc/research/d1/iod/DATA/dmi.monthly.ascii>
- Trans Nino Index (TNI), NINO3.4 (HadSST) - : http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Data/
- Statistical programming performed with R

4.5.2 Validation of SPEI with NDVI

- In Southern Africa, most of the severe droughts are associated with El Nino (Rouault, 2005). The area has regions of very different climatology and ecology, it can be misleading to compare rainfall deficit as a measure of drought. (SPEI and the Standardized Precipitation Evapotranspiration Index (SPEI) are better drought indicators How well does SPEI represent the drought impact on vegetation?



- NDVI is affected by many ecological factors including water availability. NDVI response is expected when the water deficit reaches a certain minimum threshold, depending on vegetation type, time of the season etc. Analysing the relation of vegetation status and water deficit locally can improve drought warning systems by providing information on how drought indexes can be interpreted locally.
- There are strong differences of the correlation of SPEI3 and NDVI throughout the Limpopo basin. High correlations are found in south eastern transect whereas the correlation in the north east and in the southwest are lower. Low correlations can be caused by intense irrigation within a grid cell, and/or vegetation types.
- In the Limpopo River Basin, below a value of $SPEI < -1$ vegetation is affected by drought and this can be used as drought threshold in drought early warning. However further research is required to develop a framework which incorporates such relationships to identify potential thresholds.

4.5.3 Variability of spatial drought patterns

- Spatial variability of meteorological drought within the Limpopo basin was analysed using principal component analysis on SPI3 and SPEI3
- Of 334 PCs on SPEI3, 13 explained 91 % of the total variation. Of these only the first 6 PCs sum up to 78 % of total variance.
- PC 1 shows a drought pattern with a strong south-western gradient. PC 2 shows an orthogonal north-western gradient but also has negative values along the coastline in the East. PC1 and PC2 account for 53 % of the total variation.
- PCs 3 to 5 contribute 8 %, 7% and 5 % to the total explained variation and exhibit more complex patterns. All three show patterns that divide the region in three.
- PC 5 had the highest correlation with all the climate anomaly indexes.
- SPI calculated for the Limpopo basin shows low correlation with atmospheric anomalies
- Two important aspects of teleconnections not considered in the analysis (i) sea surface temperature and (ii) time lag these need further investigation



- To identify teleconnected regions, the loadings were correlated with sea surface temperature. The ERAI -SST and the HADSST2 sea surface temperature anomaly data set were applied.
- These results support two conclusions: (i) the dominating spatial patterns cannot be linked to specific climate anomalies. Every drought event very likely is a unique combination of many factors of influence.(ii), promising regions of SST were identified, which are potential predictors, as they exhibit lead times for the Limpopo region precipitation.

TEMPORAL VARIABILITY. wavelet analysis decomposes a time series data into its frequency components

4.5.4 SPI analysis

- SPI was considered as SPEI requires estimates of evapotranspiration (ETp) which were not available.
- With higher aggregation order, the SPI time series show less power (on the wavelet power spectrum) in shorter periods. For example, the SPI1 time series has events within the low 4 to 16 months periodicity range, which are no longer present in the 18 month aggregation SPI. SPI aggregation has an effect similar to a moving average.
- SPI1 and SPI18 have power in the higher period range of 32 to 64 months. The longer periodicity is visible in the SPI18, but not in the SPI1

4.5.5 Standardized runoff index time series.

- Runoff stations with complete and long records and minimum catchment ≥ 4000 km² in the Limpopo River Basin were applied.
- In Crocodile River the decrease in runoff was also very strong between 1985 and 1995
- There was also a change in frequency during these periods. Periods with high power in the 16 to 32 month band were observed. Low power was observed during the 80s and early 90s except for Mogalakwena River which retained power in the 32 month band. This could be connected to a change in the atmospheric systems' dynamic

4.5.6 Wavelet coherency analysis.

- The analysis shows the frequencies that two time series have in common over time



- South Africa experienced severe drought during the years 1983, 1987, 1992 and 1998. These drought events also coincided with El-Nino phases. Wavelet coherence analysis shows that SPI3 shares signal properties with ENSO of periods between 2 and 4 years. Furthermore, these frequency coherencies are out of phase for the two time series.
- The power of frequency coherencies is not stable and changes over time and from one event to another. For 1987, ENSO and SPI3 time series show coherence power over a period range from 0.5 to 4 years. The 1992 drought shows a special wavelet coherence pattern with a distinct band of 4 years
- Oceanic Nino Index (ONI) has no power earlier than 1995 and later than 1995 this gap is narrowing. Consistent bands of frequency coherence with ONI – if present at all – are often interrupted during the period of 1985 to 1995. NINO 1.2 has power in the 4 to 5 years band earlier than 1995, which disappears thereafter. This suggests that different sea surface regions can complement each other.
- It is common to most wavelet coherence power spectra of runoff and climate anomaly indexes to have more segregated patterns than reanalysis precipitation. The Pienaars and Crocodile Rivers runoff has strong power on a band of approx. 8 years with the ONI index. During the 1985 to 1995 period the coherence is broken. Several events in the late 70 and late 90 show coherence with ONI in shorter periods of 4 years. The Crocodile River shows the same property in the late 90ies with coherence power over a wide range of periods. The Mogalakwena River shows power on a longer period and high power in late 90s and it also has coherence power in lower periods during the early 80s
- The Chokwe station in Mozambique SRI has high power on the 16 years band. During the 70s it also exhibits high power over a wide range of periods between 2 and 5 years but in the period between 1985 and 1995 the coherence band is changed and narrowed
- Atmospheric anomalies are known to cause drought they are at the heart of various statistical methods of rainfall prediction. This work serves as preliminary analysis to assess the complexity of drought variability.

4.5.7 Conclusions

- The following conclusions emerge from this work:



- The signals available for temporal variability of runoff and precipitation showed inconsistent properties.
- Frequencies present in the signals had only little consistency in time and space. The period 1985 to 1995 is marked by strong changes in precipitation total and signal properties.
- Some flow stations seemed to be disconnected of the ENSO during this period and signal properties strongly differed between runoff stations, which indicates that every sub-catchment has local factors that affect rainfall anomaly and some regions can be affected more by an anomaly and others less.
- Prediction models have to be able to deal with nonlinear and interacting relationships with climate anomalies. Neither could certain anomalies be associated with spatial patterns nor could certain anomalies be isolated. It is very likely that every drought event is caused by a unique combination of different atmospheric anomalies
- Correlation and wavelet analysis were important methods but correlations between variables do not imply a causal link. Rather, causally linked variables are likely to be correlated. Hence, correlation can only serve as an indication of a potential causal and above all linear link. The same is valid for wavelet coherence analysis. Wavelet coherence does not imply a causally linked relationship, nor single event wise coherences, they only highlight signal similarities in frequency space. This can only be taken as an indicator for relationships between variables.
- Methods applied such as Wavelet analysis algorithms require complete records and cannot deal with missing data

4.6 DOWNSCALED AND TAILOR MADE HYDROLOGICAL MODELS FOR THE LIMPOPO AND NIGER CASE STUDY BASINS

4.6.1 Limpopo River Basin data sources

- Digital Soil Map of the World (FAO 2003), soil types extrapolated to 0.05° x 0.05° grid cell
- Vegetation types from GLCC version 2 (USGS EROS Data Center 2002) divided into three categories: natural vegetation, rainfed crops and irrigated crops, where each category was subdivided into tall and short vegetation.



- A climatology of crop factors for the different land surfaces come with PCR-GLOBWB. Leaf Area Index (LAI) per type for dormancy and growing season obtained from Hagemann et al. (1999). An empirical relation by Allen et al. (1998) was used to convert the LAI to crop factors.
- Irrigated area within each cell, water requirements and irrigation cropping patterns extracted from the "Global map of irrigated areas" and FAO 1997
- DEM produced from the Hydro1k Africa (USGS EROS Data Center 2006) and upscaled to the model resolution of 0.05°
- ERA-Interim precipitation data corrected with GPCP v2.1
- The reference potential evaporation was computed from the recalibrated form of the Hargreaves equation Sperna Weiland et al. (2012).
- SRI computed using the software SPI SL6 developed by the National Drought Mitigation Center (NDMC) at the University of Nebraska-Lincoln, US (<http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx>).

4.6.2 Limpopo River Basin Methodology

- PC Raster Global Water Balance Model (PCR-GLOBWB) is applied.-model parameters are assumed to be correct based on the best available input data. The difference that different ensembles of meteorological forecasts may bring in hydrological model results can be expected to dominate any gains that may be achieved by calibrating the model with one set of historic data.
- New development includes an irrigation scheme to account for the highly modified hydrology in the Limpopo river basin. The model is set up for a spatial resolution of 0.05 x 0.05 degrees downscaled from 0.5 x 0.5 degrees and simulation is carried out for a 32 year-period on a daily time step
- Part of groundwater drained by surface water, is computed by assuming a linear relationship between the storage and outflow. Groundwater residence time depends on the saturated hydraulic conductivity of the aquifer the drainage porosity, the aquifer depth, and the drainage length.
- River routing is based on the kinematic wave approximation of the Saint-Venant Equation.



- Floodplains and through-flow wetlands are treated as regular river stretches except that flooding spans through the entire floodplain normally with higher resistance, which is defined in terms of Manning's n separately for the river bed and floodplain.
- Areas of lakes and floodplains are kept constant while routing.
- Irrigation water requirement for a cell is supplied through the storage of freshwater in the cell and groundwater extraction for irrigation is not considered but is feasible if information is available

4.6.3 Limpopo River Basin Results

- Output included actual evaporation; soil moisture; surface and subsurface runoff, river discharge, root stress, water storage in the three layers etc.
- Standardized Runoff Index (SRI) was impossible for gauge stations in the Limpopo River Basin to compute SRI because the runoff data was not continuous the required period of at least 30 years. Missing data reduces continuous measured data in general to about 10 years.
- Streamflow Drought Index (SDI) applies estimates of natural logarithms of cumulative streamflow with mean and standard deviation. Indices ranging from 0.0 (no drought) to -2.0 (extreme drought). The SDI allows the computation even if there are missing values.
- Similar SDI and SRI were obtained for 6 and 12 months, most flow occurs in the first 6 wet months of the hydrological year. In both cases the major droughts appear to be identified reasonably well (1982-83, 1991-92) with SDI and SRI values smaller than -1.5. Extremely wet year of 2000 is very visible with SDI and SRI higher than 2.0.
- Check cumulative runoff to complement Figures 2-14 to 2-18. Check fit for deferent flow percentiles separately ($\leq 10\%MAP$, $10\%MAP-25\%MAP$, $25\%MAP-MAP$, $>MAP$) –Fig 2-19 to 2-23. Check fit for deferent flow percentiles separately ($\leq 10\%MAR$, $10\%MAR-25\%MAR$, $25\%MAR-MAR$, $>MAR$)

4.6.4 Niger River Basin Data

- Digital elevation model of adequate resolution



- WATCH is a global sub-daily meteorological forcing dataset as derived from the ERA-40 reanalysis for period mid-1957 to 2001. ECMWF and CCAM weather forecast products
- CRU TS2.1 Climate Research Unit gridded flow station observations
- Digital Soil Map of the World (FAO et al., 2009) <http://www.fao.org/geonetwork/srv/en/metadata.show?id=141116&currTab=distribution>
- Harmonized World Soil Data Base v1.1 <http://www.iiasa.ac.at/Research/LUC/External-World-soildatabase/HTML/index.html>
- GPCP product v4monthly precipitation observations
- 88 rainfall stations from the DNM (Direction Nationale de la Météorologie Malienne)
- Global land cover <http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php>
- Shuttle Radar Topography Mission (SRTM) data - <http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php>

4.6.5 Niger River Basin Methodology

- Soil and Water Integrated Model (SWIM) was set-up on the Intermediate Niger Basin and calibrated to represent region specific processes, stocks and fluxes by using regional ground-truth and remote sensing data. Further developments include reservoir management, wetlands and inundation plain dynamics. In the INB interaction between wetlands and lakes and inundation are important. The reservoir module allows for release for minimum flows, managed releases and energy releases.
- Hydrological response units have same properties (soil and land use/cover) regarding bio-physical processes. The model is connected to meteorological, land-use, soil, vegetation and agricultural management input data. Simulations consider water balance for four control volumes: the soil surface, the root zone, the shallow aquifer, and the deep aquifer. The percolation from the soil profile is assumed to recharge the shallow aquifer. Return flow from the shallow aquifer contributes to the streamflow. Shallow aquifer water balance includes ground water recharge, capillary rise, lateral flow, and deep percolation



- Inundation module simulates release and flooding, the flooded surface area, inundation depths, and duration, evapotranspiration and percolation
- Calibration and validation with PEST (Model-Independent Parameter Estimation and Uncertainty Analysis): <http://www.pesthomepage.org/> for period 1971-1980 and 1982-2000

4.6.6 Niger River Basin Results

- Model performed well on estimation of runoff, flow frequency, overestimation of the annual peak and over-estimation of low flows
- The model is being extended to model drought conditions

4.7 LOCAL SCALE AGRICULTURAL MODELS

4.7.1 Limpopo Basin Data

- Yellow and white maize yield data obtained from the South African National Department of Agriculture, Directorate: Statistics and Economic Analysis. Data are available from 1981 to 2011.
- Focus on Witbank and Middelburg agricultural districts and the Rustenburg agricultural district
- ECMWF System 4 data

4.7.2 Oum-er-Rbia Basin data

- Durum wheat data obtained 2stations in the coastal region, 4 stations in plains (and 3 stations in the mountains. Data are available form 1979-80 through 2007-2008.
- Sowing dates: October-November November-December February Harvest dates: May May-June August
- ECMWF System 4 data
- Method
- The crops of both basins considered here are strongly rain-fed, so the assumption is made that if a global model is able to predict seasonal rainfall over an area of interest, then the same global model's output can also be used in a statistical forecast system to predict a rain-fed commodity such as crops. An assumption is made that if a global



model is able to predict seasonal rainfall over an area of interest, then the same global model's output can also be used in a statistical forecast system to predict a rain-fed commodity such as crops.

- A downscaling modelling system to predict seasonal crop yields over the Limpopo (southern Africa) and Oum-er-Rbia (Morocco) river basins.
- ECMWF System 4 data transformed from GRIB into the format required by the statistical software package used in the analysis. Ensemble mean data and 3-month averaged sea-level pressure (SLP) and 850 hPa geopotential height data are the predictors considered.
- ECMWF S4 low-level circulation data for the three-month season prior to the period of harvesting is transformed into normal distributions then post-processed into to crop using the model output statistics (MOS). MOS equations are developed by using the principal component regression (PCR;) option of the Climate Predictability Tool (CPT) of the International Research Institute for Climate and Society (IRI; <http://iri.columbia.edu>)
- The low-level circulation fields of the ECMWF System 4 (S4) are used as predictors in a principal components regression (PCR) approach to test the predictability of seasonal crop yields over the two basins. The models are tested over a 26-year period to determine their deterministic skill levels, as well as over a 16-year retro-active forecast period to test their probabilistic skill capabilities.
- The three-month season prior to the period of harvesting is selected based on the assumption that the seasonal averaged low-level circulation during that three-month period is associated with the rainfall over the region of interest and hence related to the production of dry land crops. Limpopo DJF hindcast are used throughout, and for Oum-er-Rbia, both FMA (for coastal and plains) and MJJ (for mountains) hindcasts are used.
- The hindcast fields used in the MOS equations are restricted over a domain that covers an area between the equator and 45°S and from 20°W to 60°E for the Limpopo downscaling, and from 40°N to 30°S and from 150°E to 20°W for Oum-er-Rbia downscaling
- Deterministic skill is determined over a 26-year period for the harvest years of 1983 to 2008



- Cross-validation is performed with a large 5-year-out design to minimise the artificial inflation of skill. Retro-active forecasting is applied over the 16-year period from 1993 to 2008 to produce a set of probabilistic downscaled hindcasts
- o The relative operating characteristic (ROC) was used to test for systematic discrimination and as a verification measure, and the reliability diagram was used to determine if the confidence communicated in the hindcasts is appropriate. If the area below ROC curves is ≤ 0.5 , the model discriminates correctly only for less than half the time. For a maximum ROC score of 1.0, perfect discrimination has been obtained.

4.7.3 Limpopo Results

- Significant forecast skill was mainly restricted to the Rustenburg agricultural district. Agricultural district yield indices (normalised values)
- Discrimination was achieved, especially for the Rustenburg agricultural district, but the ability to predict for high yields for this district is restricted to lead-times up to two months. useful skill for Rustenburg can be seen for both high and low yields at short lead times.
- Good reliability for the prediction for low yields (a consequence of drought) can be seen for Rustenburg (middle panel), but over-confidence is found in predicting high yields for all three districts.

4.7.4 Oum-er-Rbia Results

- Skill may be found for the mountains and coastal areas, but very low predictability is seen over the plains of the basin.
- Probabilistic skill suggests potential for making yield predictions over the mountains and over the coastal areas. Poor skill was found over the plains
- Good discrimination was found in mountain areas and for high yields. At a 2-month lead-time, high and low yields are well discriminated for both the coastal and mountain areas, and so we will present a reliability analysis of the forecast system at this lead time only. There was good reliability for predicting low yields over the mountain and coastal areas, but the prediction of high yields has been found to be over-confident



4.7.5 Overall

- This study presents a baseline that needs to be outscored by such sophisticated approaches. Examples of these approaches include the use of physical crop models that assimilate output from global climate models on temporal and spatial scales reconcilable with their requirements.

5 IMPLEMENTATION OF IMPROVED METHODOLOGIES IN THE CASE STUDIES (WP6)

5.1 THE CASE STUDY CONTEXT

5.1.1 Nile River Basin

- On the Nile, the main models used in this case study are the Regional Climate Model (PRECIS) and the Nile Forecasting System (NFS). PPRECIS implements dynamic downscaling based on the HADCM output while the NFS involves real-time hydro meteorological monitoring, forecasting, and simulation system for the Nile River basin: Compare SPI in both ERA40 and CRU data. Climate change scenarios output are used in SPI calculations. Results of NFS for Blue Nile and Atbara basins with CC scenarios output are analysed.
- Results from the CC scenarios are compared with CRU and ERA40

5.1.2 Limpopo River Basin

- Regional drought SPI distribution for the Limpopo basin and Severity Areas Frequency curves from SPI3 and SPI9 for the Limpopo basin.
- Seasonal statistical forecasting of runoff for selected stations
- Evaluation of ERA-Interim drought indices with NDVI (Modis)
- Evaluation of indigenous knowledge and formal forecasting methodologies (working with communities and MET Departments). Validation stage for the Mzingwane catchment based on the identified indigenous parameters.
- SPI-NDVI methodology (working with SAWS and CSIR and ARC) in Luvuvhu Water Management Area to assess the use of remotely sensed data (NDVI and VCI) together with topographical attributes (Aspect, slope and Altitude) to improve applicability of SPI.



- Detailed implications of drought of vegetation, crop yield, hydrology
- Refining forecasting and tailored forecast products (Livestocks and crops)
- Institutional flow of information at regional and national level, options for improvement

5.1.3 Oum Er Rbia River Basin,

- There are no early warning systems,
- Constraints for the establishment of an early warning system:
 - Data exist, but are non available (accession problems).
 - Measurement networks exists, but have to be densified and modernised.
 - As for the data treatment, the existing structures need a scientific-technical partnership.
 - The dissemination of information is localised and restricted, and a lot of information is not public
- The preliminary analysis of the results shows:
 - The forecasts are not able to detect rainy days 15 days ahead. Indeed, among all the rainy days analysed, none of the forecasts was able to predict either the occurrence of rain or the amount of rain (whatever it was a small, moderate or important rainfall amount).
 - Forecasts seem good to predict dry periods, as shown by the fairly good concordance between the observed rainfall and the 50 percentiles.
 - Concerning rainy days, the results show that globally, they are not detected from 10 to 15 days ahead. In the best cases, the occurrence of rain starts to be forecasted around 6 days ahead. However, this is not verified for all the forecasts. Then, even when the rainy episodes are forecasted, the amount of rainfall is very often underestimated, especially for important rainfalls.
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5.2 THE PAN-AFRICAN MAP SERVER

- Temporal correlation of between TRMM and ERAI for SPI3, SPEI3, SMA and PET shows varied performance, with PET performing poorly. Correlation between TRMM and GPC for SPI3 and SPEI3 also showed varied performance. Best performing areas had correlation coefficients of 0.5 to 0.6 and these comprised the Zambezi River Basin , Great Lakes region and Eastern Nile and North Africa around the Mediterranean coast of Morocco, Algeria and Tunisia. The rest of Africa performed poorly.
- Monthly anomalies in SPI-3 (ERAI, GPCP, TRMM), SPEI-3 (ERAI, GPCP), SRI3 (ERAI) and SMA (ERAI) for January 2008 do not show the same picture for most parts of Africa with SRI3-ERA showing the greatest difference from the other anomalies .
- Fractional area of each region under SPI-3 bellow -1.0 (drought conditions) from 1998 to 2010 from ERAI, GPCC, GPCP, TRMM is in general agreement with observed conditions in WP2, D2.2 for the extremely dry years but less dry years show poor results.
- Inter-comparison of a set of hydro-meteorological indicators in order to set up a Pan-African map server. Between the indicators analysed are included the Standardized Precipitation index (SPI), Standardized Precipitation-Evaporation Index (SPEI), Standardized Run-off index (SRI), and Soil Moisture Anomalies (SMA).
- Vulnerability and risk analysis were performed at continental and regional level, these scales are very coarse better products are available from FEWSNET-regional and local vulnerability assessments.
- Pan-African Map Server presents drought relevant information for entire African continent based on data processed and analysed at JRC. Drought products could include monthly updated Standardized Precipitation Index (SPI), daily updated modeled soil moisture anomalies, 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)).

6 CONCLUSIONS

The framework for drought warning and mitigation in Africa proposed can assist in establishing policy priorities based on scientific evidence that also strengthen existing



institutions. Overall, a science-based approach is a useful guideline, but a number of challenges are recognized. Risk-based approaches to preparing for drought are focused on acquiring accurate probabilistic information about the events themselves. When this is not possible, the strategy fails. In contrast, understanding and reducing vulnerability does not demand accurate predictions of the incidence of extreme drought. Nevertheless, it may be politically difficult to justify drought vulnerability reduction on economic grounds.