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

(DEWFORA)

A 7th Framework Programme Collaborative Research Project

Work Package 2

Assessing existing drought monitoring and forecasting capacities, mitigation and adaptation practices in Africa

DELIVERABLE 2.4–GAP ANALYSIS REPORT ON DROUGHT MONITORING AND FORECASTING SYSTEMS IN AFRICA

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EXECUTIVE SUMMARY

*This document assesses the gaps between "**state of the art"** and current practices for local, regional and continental **drought** monitoring, forecasting, **warning and response systems in terms of monitoring and forecasting inputs, outputs and resources in Africa**.*

The Group on Earth Observations defines a "state of the art" early warning system as: "a web-based, real-time Geographic Information System GIS server with a distributed database federation, used for hydrologic alerts in drought conditions..." Monitoring, forecasting and early warning systems in the USA, Australia and Europe are provided as examples of "state-of-the-art" systems.

For the "state-of-the-art" systems responsibilities for drought monitoring, forecasting and early warning are distributed among different institutions, with the number of institutions decreasing when moving from in-situ observations (level 1) to development of tools (level 4). The levels of responsibility are 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.*

*Monitoring of drought is done either in-situ or using satellite technology. **Satellite-based drought monitoring** products include AVHRR, MODIS, GRACE, SRTM and AATSR.*
*In-situ flow of data is send from **observation networks to databases** regularly to a database via the internet or satellites. Similarly, satellite imagery is received at regular intervals. Checking and post-processing introduces a time lag between measurement and delivery to public or private databases.*

*Once the data is checked and available in public and private databases, other institutes might access the data. Web-based technology is used to obtain data from the **databases to institutional servers**. Some data from monitoring networks and databases are also available in the public domain by agreement or some arrangements to ensure that changes* *in data delivery which may occur do not disrupt monitoring and forecasting. Public web-data access can be anonymous or through a login file transfer protocol.*

*Geodata is managed with online servers such as ArcGIS server and **Geoserver**, an open source Java server designed for sharing and editing geospatial data. The different systems are able to get data from and put data into remote or local locations. They are able to work with many different data formats and they use web standards, such as: **Web Feature Service (WFS)** and **Web Coverage Service (WCS)** standards, as well as a high performance certified compliant **Web Map Service (WMS)**. **KML**, an xml format developed by Google is also applied. **NetCDF** is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. Institutions use these standards, systems and programming languages to access data and to store it in their own online or offline databases, after which their own models can access it, make runs for forecasting, or can post-process the data for informative visualisation.*

*Data is processed using **GIS tools and models**. Data is processed to produce several indices, which are then used for monitoring and forecasting drought. For monitoring, the indices are calculated with observed data. **GIS tools** used include GrADS and ESRI ArcGIS. Models applied include VIC, NLDAS, Leaky Bucket and WaterDyn. Algorithms applied include 3-D spline and Cressma. Data formats used include NetCDF, ASCII grids, ESRI grids and GRIBS file-types. CSV is often used to provide tabular data, or per-station-data. More general files use gif and pdf formats while gif and png are often produced by WMS services.*

The Bureau of Meteorology (BOM) and SILO provide gridded weather data at 0.05 degree. Observed data in Australia allows an accuracy of 0.01 degrees (approximately 1km). NLDAS is used at 1/8 degree (14 km in North America). AVHRR products often have a resolution of 4km. RangeView provides applications for viewing, animating, and analysing satellite imagery in order to monitor vegetation dynamics through time and across landscapes. The viewer shows AVHRR NDVI products from 1989 to 2008 and MODIS NDVI products from 2000 to 2006.

*Climate data are often provided in **near-real time** or at daily intervals. The smallest time-interval for the delivery of drought information is often weekly. Monitoring information will often provide averages for the past week, 2 weeks, month, season, half year, year, 2 or 3* *years. Forecasting efforts use the same time-frames but there is a lot of uncertainty when trying to forecast drought beyond a future window of 3 weeks from the present.*

Information is made available to the public and policy makers as views, which vary in complexity form from simple to sophisticated. Some often-used OGC standards for geodata are available from the internet. Information is shared through web-browsers and so-called geoweb applications. These capabilities can be obtained together with the server-technology used, but this is not always necessary, because most servers can deliver data in the formats and standards the user desires. WFS, WMS, WCS, KML and NetCDF are all OGC standards that most geo-servers can work with. ESRI for example provides some geoweb applications for use in conjunction with their server, but these obtain their data in the same way as other open source webmap applications would. ESRI's servers are also capable of producing streams of data, for example in JSON, AJAX, Python, PHP, Java script or active-script. These formats can be used in conjunction with other web-languages. Other servers are probably capable of the same thing. More sophisticated visually attractive and interactive websites developed for internet have led to new technologies such as JSON, AJAX, Python, PHP, Java script, active-script and flash. An often used and very effective way of serving maps via the internet is simply to link to 'flat' images and a web form to select the correct image. This is a simple and effective way, which doesn't require a complex infrastructure. At the other end of the spectrum are complex, sophisticated viewers that take in data streams and create viewers which serve their data in separate layers, allowing users to customize their views.

A framework to address user requirements for drought monitoring and early warning was developed. 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 focussing 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 comparative analysis considers selected basins in Africa namely: the Oum-er-Rbia River Basin, (Morocco), Eastern Nile Basin (Burundi, Egypt, Ethiopia, Kenya, Rwanda and Sudan were included), Limpopo Basin (only South Africa and Zimbabwe were included) and part of the Niger Basin in Mali. The main users of drought monitoring and forecasting systems and their requirements were obtained from deliverable D2.3.*

The main users of drought monitoring and forecasting systems in Africa are as follows:

Oum er Rbia Basin	***Nile Basin***			***Limpopo Basin***		**Niger Basin**
Morocco	***Ethiopian Plateau***	***Downstream Countries***	***Equatorial Lakes Region***	***South Africa***	***Zimbabwe***	**Mali**
• *Farm organizations* • *Agribusinesses* • *Regional and national farm policy makers* • *Government agencies* • *Research institutions* • *Crop and livestock producers*	• *Line ministries and humanitarian agencies* • *Government, donors and the international community.* • *Local government officials* • *The federal level, and Woreda officials* • *Early Warning response directorate(EWRD)* • *Save the Children UK* • *Household Economy Approach (HEA)* • *FAO* • *DPPC's Early Warning Working Group* • *IGAD Climate Prediction and Applications* • *Centre (ICPAC)* • *Humanitarian Early Warning Service (HEWS)*	• *Nile Water Sector* • *High Aswan Authority* • *Water Management and Distribution Sector* • *Irrigation Sector sub-Sectors* • *Development Irrigation and Nile protection Sector* • *The Council of Ministers* • *Ministry of Irrigation and Water resources* • *Ministry of Agriculture* • *Ministry of Humanitarians Affairs* • *Ministry of Animal Resources*	• *Meteorological offices or agencies* • *Early warning systems organisations or offices* • *Disaster management organisations or offices* • *(FAO, UNICEF, NGOs, etc.)* • *National government agencies responsible for resource planning and emergency interventions for droughts and floods.* • *Various research institutes and universities*	• *Department of Water Affairs* • *Department of Agriculture* • *Municipalities* • *Catchment Management Areas* • *Water Users Association* • *Disaster Management Centres* • *Food and Nutrition Council.* • *Parliamentary Portfolio, Committee on Lands, Agriculture, Water Development, Rural Resources and Resettlement, President's Office,*	• *Government* • *Farmers* • *Local rural leaders* • *Agri-business* • *Agri-Bank* • *Media* • *NGO's* • *Funders*	• *Farmers, herders, fishermen* • *All those involved in fish industry* • *Socio-economic organizations and local communities, NGOs,* • *Technical Services of the State and NGOs, decentralized services of the state, rural and urban districts* • *Farmers*

The main requirements for users of drought monitoring and forecasting systems in Africa are as follows:

Oum er Rbia Basin	***Nile Basin***			***Limpopo Basin***		**Niger Basin**
Morocco	***Ethiopian Plateau***	***Downstream Countries***	***Equatorial Lakes Region***	***South Africa***	***Zimbabwe***	**Downstream Countries**
• *Seasonal drought forecasts.* • *Weather related developments and their effects on crops and livestock* • *Indicators on climate, water and soil parameters and socio-economic coupled to fully characterize drought magnitude, spatial extent and potential impact* • *Length of the dry spell* • *More reliable operational and monitoring information* • *Usable information related to intervention options* • *Information from early warning systems should support policy development for poverty and livelihood issues, crop production forecasts and trade policy.*	• *Early warning information which talks to zonal and regional systems* • *A more unified, transparent, coordinated, and objective early warning system, that has a system of "checks and balances."* • *Improved data collection at the local level* • *A multi-hazard early warning system* • *More reliable monitoring information.*	• *Better understanding of climate variability, and improved management of its associated risks.* • *Timely dissemination of information to end users in suitable format.* • *A well coordinated end user's network.* • *Availability and flow of data on a sustainable basis* • *Regional drought monitoring and forecasting plans* • *Identification of expected drought events before a drought takes place* • *To link early warning system and drought, desertification*	• *Response plans for the lives of crops and people due to shortage of food and water* • *Response plans for the lives of animals due to shortage of food and water* • *Data for strategic planning and emergency interventions for droughts and floods.* • *Seasonal plans and advice for socio economic activities* • *Detailed weather and climate information as well as development of climate models*	• *Identification of expected drought events before they occur* • *Better interpretation of results from drought forecasts* • *Early warning on impact of drought on the livelihoods of local communities* • *Length of the growing season (start and end of the rainy season)* • *A tool that that translates the forecast into information on the availability of water in rivers and dams* • *Easy to understand information (communicate risks of forecast clearly to enable users incorporate this information into their own risk management frameworks)*	• *Improved data sharing between government agencies and research institutions,* • *Reduced cost data limits as this limits its application in drought monitoring, preparedness, mitigation and response;* • *Less technical and more usable information from early warning systems* • *Users have experience with occurrence of rainfall, therefore the spatial scale for predictions should consider variability of rainfall*	• *More research and knowledge development in the field of weather and climate.* • *Improved dissemination of weather and climate information* • *Improved application of forecast information*

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, 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.*

The following parameters make the ***input data*** *for "state of the art" drought monitoring systems:*

Parameter	***Method/Technique***	***Expected Outcome***
Vegetation	• *Integration of coarser-resolution vegetation and climate data* • *Integration of higher-resolution, satellite-based vegetation observations and socio-economic and ecological data*	• *Wide coverage in terms of area, can zoom into specific area and provides information on local variability of drought and effect on vegetation conditions* • *High spatial intensity, and local variability of drought impacts*
Rainfall	• *Telemetry system from rain gauges* • *Remote Sensing* • *Google Earth* • *Templates* • *Obtain from real time national weather services*	• *Ability to communicate with existing networks and also new channels in order to obtain more data. In case where data can be obtained from existing real time networks such as weather services* • *Loading of satellite images for comparison purposes and can also be used to analyze the soil water holding capacity* • *Real time pictures after the rain which can be used to analyze the soil water holding capacity* • *Ability to capture manual data in a template because not all area have communication links for direct transmission of data into the system*
Temperature	• *Telemetry system* • *Remote Sensing* • *Obtain from real time national weather services* • *Templates*	• *Images should be used when historical analysis is performed* • *Received images should be viewed and analysed for historical and current data.*

Parameter	Method/Technique	Expected Outcome
Storage	• *Images* • *Telemetry system* • *Obtain data from existing am monitoring stations*	
Soil Moisture	• *Use satellite sensors for different activities*	
Total runoff		
Stream flow		
Evapotranspiration	• *Based on satellite radiation, temperature and vegetation data, gravity recovery measurements of changes in water storage, microwave based retrievals of soil moisture and altimetry based estimates of lake levels and river flows*	
Socio Indicators		• *Ability to capture socio indicators. This can be used for analysis on when and how droughts occur.*
Forest fires	• *Use remote-sensing data in the form of satellite images.*	• *Real-time capturing of forest files to allow the determination of the extent of the drought.*

A comparative analysis of the ***outputs between*** *"state of the art" and drought monitoring systems in Africa shows the following:*

For ***Morocco*** *Accumulated precipitation, stream flows, runoff, water balance, water table, soil moisture, SWSI, RAN, SPI, PSDI, NDVI, SVI, VCI, TCI and VH are produced. The frequency of output indices is daily, decadal, monthly and annually.*

An evaluation of 8 institutions involved in drought monitoring shows the following:

- *Most institutions produce precipitation, temperature parameters*
- *SPI is the index mainly calculated*
- *All institution produce bulletins for information dissemination*
- *Indices are produced monthly annual and decadal*

On the ***Nile River Basin*** *meteorological information is produced at different frequencies and spatial scales. Maps and periodical reports are produced at regional and national level for different users at different frequencies (monthly and annual).*

In ***Southern Africa*** *meteorological bulletins with average seasonal temperatures, accumulated precipitations for the season, SPI, rainfall, moisture index, land use and elevation are produced. Drought monitoring systems produce a limited number of indices at inappropriate scales, which means that there is a narrow range of possible users. For* *example, in South Africa, the SPI is produced but the spatial scale is to course for most users. Some data is also provided on river flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions and water entitlements and water traded.*

A comparative analysis of the ***inputs*** *into "state of the art" and drought monitoring systems in Africa shows that in the USA, Europe and also in Africa meteorological data is mainly used as an input data to the models. Meteorological Departments in Africa provide data to the ECMWF in Europe. 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. The main challenges to monitoring of drought in Africa are as follows:*

- *Meteorological and hydrological data networks are often 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.*

A comparative analysis of the ***resources*** *available for "state of the art" monitoring systems and for those in Africa shows that the USA, Australia and countries in Europe have high quality equipment and are better funded. In Africa the infrastructure is poor (equipment, software, monitoring stations network not covering all areas, no weather RADAR stations etc.). In addition financial resources are very limited and financing data collection is not a high priority for national governments. The high cost of data is done to try and generate funds for operations.*

A comparative analysis of the ***outputs*** *from "state of the art" and drought forecasting and early warning systems in Africa shows that the USA and countries Europe produce products from remote sensing for users who need them and actually use them. Examples of outputs/products from "state of the art" drought forecasting and early warning systems include the following:*

- *Temperature and precipitation (6-10-day, 8-14-day. 1 month, 3 months)*

- *Hazard outlooks (3-7 day, 8-14 day, contours)*
- *Variable infiltration capacity (VIC)*
- *Keetch-Byram drought index and Palmer index*
- *Precipitation at representative monitoring stations*
- *River flow at representative hydrometric monitoring stations*
- *Reservoir discharges and groundwater tables*
- *Surface water balance*
- *Water stored in the form of ice and permafrost*
- *Drought evaluation features, which apply indicators to assess the regional situation in terms of the following:*
    - *Meteorological scenarios and potential rainfall scenarios;*
    - *Estimates of water availability based on modelling;*
    - *Possible water deficits for the existing water uses and estimates of possible socioeconomic and environmental impacts* for the current year;
    - *Recommendations to farmers, water companies and other users the actions to adopt for to withstand the potential impacts drough;t*
    - *Drought risk maps with a simple classification of droughts risk (normal, moderate, high) for geographically and environmentally defined regions or catchments;*
    - *Hydro climatic aspects of drought which consider the natural/physical systems;*
    - *How meteorological droughts will propagate into hydrological droughts;*
    - *Socio-economic Impacts; economic and social effects of droughts, Water demand- and supply management for the key sectors: agriculture, energy production, residential water use, water-intensive manufacturing.*
- *Environmental variables to enhance understanding of:*
    - *how impact of drought is influenced by ecosystem structure;*
    - *how drought alters key ecological functions for the preservation of water quality and habitat integrity;*
    - *which flow conditions are required for reducing ecosystem sensitivity to drought.*
- *A drought alert and severity classification, which tries to represent the real impacts and the level of interventions required to reach tolerable levels.*

In Africa, the number of users of similar 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 early warning products that they can use.*

The input data for Global and "state of the art" early warning/forecasting systems include the parameters for "state of the art" monitoring systems as well as the following:

- *Solar radiation, air temperature, maximum and minimum temperature;*
- *Daily gridded SPI;*
- *Rainfall, rainy versus dry days;*
- *Vegetation health, NDVI;*
- *Volumes stored in reservoirs;*
- *Groundwater levels;*
- *Consumption requirements for the main water users;*
- *Atmospheric forcings;*
- *Elevation, land use/cover, soil information;*
- *Routing networks;*
- *Socioeconomic parameters related to assessment of drought impact;*
- *Human activities, which have an impact on vulnerability to drought.*

Drought early warning/forecasting systems in Africa apply the following input data:

- *Temperature (minimum & maximum), wind direction, wind speed, solar radiation, rainfall, air pressure, sun shine hours, relative humidity, evaporation;*
- *Cloud imagery (CCD) from IGAD& ICPAC, WMO;*
- *NDVI (from FAO).*

A comparative analysis of the ***inputs*** *into "state of the art" early warning/forecasting systems and those in Africa shows that the following challenges for Africa are:*

- *Dependency on a limited number of data sources/providers.*
- *Unsustainable data flow*

A comparative analysis of the ***resources*** *available for "state of the art" early warning/forecasting systems and those in Africa shows that the USA, Australia and countries in Europe have "state of the art" computers, servers and software. In Africa the infrastructure is poor (equipment, computers, software, etc.). There is a gap of enough skilled technicians, professionals and researchers to handle weather and climate information. 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.*

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. 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.

The following observations were also made in this deliverable:

- *The forecasting and early warning systems available in Africa are not adequately maintained; recalibration and troubleshooting of the systems are also 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 therefore not appropriate;*
- *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.*

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LIST OF ABBREVIATIONS

AATSR	Advanced Along Track Scanner Radiometer
ABHs	Hydraulic Basin Agencies
ACIS	Applied Climate Information System
ADI	Aggregate Dryness Index
AGRHYMET	Regional Training Centre for Agro-meteorology and Operational Hydrology
AVHRR	Advanced Very High Resolution Radiometer
BOM	Bureau of Meteorology
CARE	Cooperative for Assistance and Relief Everywhere
CCD	Clod Cloud Duration
CFU	Commercial Farmers Union
CRTS	The Royal Center of Remote Sensing
DGH	General directorate of Hydraulics
DHA	Department of Humanitarian Affairs
DMC	Drought Monitoring Centre
DMCSEE	Drought Management Centre for South-Eastern Europe
DMN	National Directorate of Meteorology
EAC	East African Community
EAC	East African Community
EMC	Environmental Modelling Centre
ENSO	El Niño – Southern Oscillation
EWRD	Early Warning and Response Directorate
FAO	United Nations, Food and Agricultural Organization
FEWSNET	Famine Early Warning Systems Network
GEO	Group on Earth Observations
GOR	Government of Rwanda
GOR	Government of Rwanda
GOZ	Government of Zimbabwe
GTZ	German Agency for Technical Cooperation
HEA	Household Economy Approach
HEWS	Humanitarian Early Warning Service
HPRCC	High Plains Regional Climate Centre
ICPAC	IGAD Climate Prediction and Applications Centre
LDCF	Least Developed Countries Adaptation Fund under the Global Environment Facility
MEDROPLAN	Mediterranean drought Preparedness Plan

MSD	Meteorological Services Department
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite Data and Information Service
NEWU	National Early Warning Unit
NFC	Nile Forecast Centre
NGOs	Non-Governmental Organizations
NMA	National Meteorological Agency
NOAA	National Oceanic and Atmospheric Administration
PDSI	Palmer Drought Severity Index
PRESAO	Seasonal rainfall forecasting in West Africa
RAB	Rwanda Agriculture Board
REMA	Rwanda Environmental Management Authority
RMS	Rwanda Meteorological Service
ROA	Regional Offices of Agriculture
RRC	Relief and Rehabilitation Commission
RRSP	Regional Remote Sensing Project
SADC	Southern Africa Development Community
SAP	Early Warning System
SARCOF	Southern Africa Regional Climate Outlook Forum
SAWS	South Africa Weather Services
SPI	Standard Precipitation Indices
SPIAC	Prediction System of Information and Early Warning on floods in the Inner Niger
SST	Sea Surface Temperature
SSWE	State Secretary for Water and Environment
SWI	Soil Water Index
UN	United Nations
UNDP	United Nations, Development Programme
USAID	United States agency for International Development
VAC	Vulnerability Assessment Committees
VAM	Vulnerability Analysis Mapping
WATCH	Water and Global Change
WRSI	Crop Water Requirement Satisfaction Index
ZINWA	Zimbabwe National Water Authority

1 INTRODUCTION

In this deliverable “state of the art drought monitoring and forecasting systems” are defined. Examples from Australia, America and Europe are given using the format applied in deliverable D2.1. A gap analysis is then conducted by comparing these with the drought monitoring and forecasting systems in Africa captured in the factsheets and detailed descriptions in deliverable D2.1. These systems cover the Oum-er-Rbia River Basin, (Morocco), Eastern Nile Basin (Burundi, Egypt, Ethiopia, Kenya, Rwanda, Sudan and Tanzania), Limpopo Basin (Botswana, Mozambique, South Africa and Zimbabwe) and Niger Basin (Algeria, Benin, Burkina-Faso, Guinea, Ivory Coast, Mali, Niger and Nigeria). These river basins are shown in Figure 1). This deliverable also picks up users of early warnings from the historical drought experiences described in Deliverable D2.3 and assesses their information requirements to further inform the gap analysis.

This deliverable addresses one of the objectives of Work Package 2, to *identify gaps/opportunities to improve drought monitoring and forecasting capabilities by using experience from globally available state-of-the-art.*

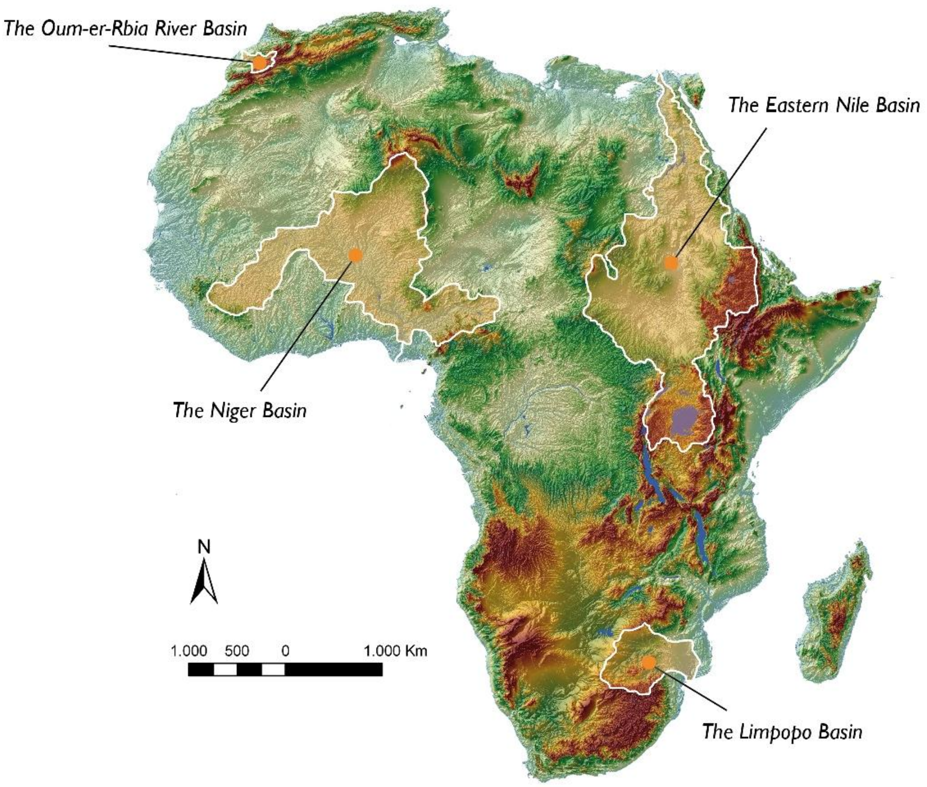

Figure 1: Location of case study basins

2 IMPORTANT DEFINITIONS

The following definitions apply to this document (as in deliverable D2.2):

- **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 WHAT CONSTITUTES A STATE-OF-THE-ART DROUGHT MONITORING AND FORECASTING SYSTEM?

The Group on Earth Observations (GEO) is a voluntary partnership of governments and international organizations which is coordinating efforts to build a Global Earth Observation System of Systems, or GEOSS. As of March 2012, GEO's Members include 88 Governments and the European Commission. In addition, 64 intergovernmental, international, and regional organizations with a mandate in Earth observation or related issues have been recognized as Participating Organizations (http://www.earthobservations.org/about_geo.shtml). Pozzi *et al* (2001) in the GEOSS Engineering report, describe a "state of the art" early warning system as: "a web-based, real-time Geographic Information System GIS server with a distributed database federation, used for hydrologic alerts in drought conditions..."

3.1 INTEGRATION OF MONITORING AND FORECASTING SYSTEMS

The US and Australia early warning systems combine monitoring and forecasting but present them as separate products. This is not surprising as monitoring data gives the present condition and allows the forecasting system to be continually recalibrated, preventing run-away results, i.e. ever increasing errors in the forecasts due to erroneous boundary conditions.

3.2 FROM MONITORING TO FORECASTING TO PUBLIC INFORMATION

In the US and Australia not all institutions involved in monitoring also provide forecast information. Taking these systems as "state-of-the-art", the responsibilities for drought monitoring and forecasting can be presented in a diagram as shown in **Figure 2**. These responsibilities are explained further in the following section:

(a) Level 1 Institutions

It is quite evident that many smaller institutions may be involved in monitoring hydrologic conditions in the areas or river basins that they are responsible for, without necessarily providing forecast information. These institutions are at the base of the pyramid and they are often responsible for natural resources management or provide public services. Often, these smaller institutions closely monitor with in-situ material developments in hydrologic and climatic conditions. They may store this information in their own databases and provide it together with outlooks, as a service. Examples of these institutions are the Bureau of Reclamation and several Bureaus of the U.S.A. Army Corps of Engineers.

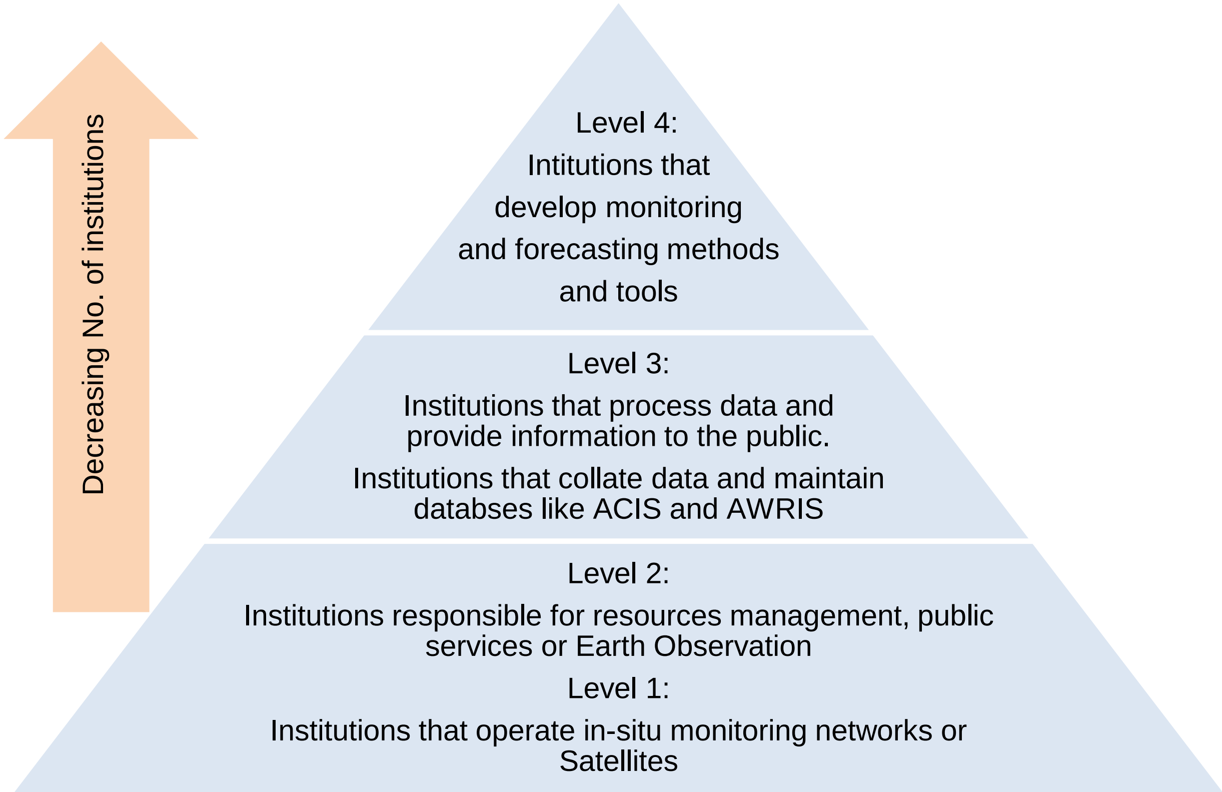

Figure 2: Spread of institutions on identifies roles on drought monitoring and forecasting

(b) Level 2 Institutions

In Australia, all institutions that either use or manage water resources are required by law to provide water information to the Bureau of Meteorology.

In the US information is shared with institutions higher in the pyramid but without similar regulation. There are institutions at national and sub-national level to spread the coverage, for example, NOAA has regional Climate Centers, each of which are responsible for a part of the U.S.A. Apart from in-situ data from monitoring-networks, data is also collected from satellites via remote sensing. The AVHRR products for vegetation monitoring are produced by NOAA and several products like MODIS and GRACE are available from NASA. Although these institutions are in the US their data is often of global extent and is also used by Australian institutions.

(c) Level 3 Institutions

There are institutions that combine in-situ data available from sub-national or national databases with information from other sources, like satellite information. These institutions perform operations on the data, calculating indices for drought monitoring, forecasting or both. To do this in real-time, an architecture, which allows automated processes, is necessary, often combined with a database to contain the data and results of forecasting runs. Often an online viewer is part of this architecture allowing disclosure of both the original information and results to the public and policy-makers.

(d) Level 4 Institutions

Research institutes like universities and institutes like CSIRO develop methods and tools for drought monitoring and forecasting. They often create methods and tools for operational systems complete with data transfer methods. As the purpose of these institutes is research, they often develop experimental monitoring or forecasting products, which are later transferred to a governmental organisation which becomes responsible for the operational phase of the product.

In the U.S.A., drought forecasting and monitoring at the national level is undertaken by a range of institutions, resulting in a range of different products relevant to drought monitoring and forecasting. Many of these institutions create their own stand-alone products, which do not necessarily depend on products of others. Other products are the result of collaboration between different institutions, which work together and share their data to make combined/derivative products. The large range of drought monitoring and forecasting products available in the U.S.A. is not the result of a single, automated system of data- and workflows. However, in their presentation to the public, effort is made to make them easily accessible via a single portal namely the NIDIS. The NIDIS only gives an overview of the main efforts in drought monitoring and forecasting in the U.S.A. and links to the websites of the respective institutes. The NIDIS portal is very useful for gaining insight in how drought monitoring and forecasting is done in the U.S.A., but it is in itself not a system.

In order to provide real-time information, or regular forecasts to the public institutions need access to each-other's data. The technical details of how data flows can be organized and types of databases, models etc. used by the different institutes are described in the next section. The AWAP project described in **Appendix A** fact sheet No. ND N 04 provides a clear example of the infrastructure for data processing.

3.3 WHAT ARE THE ESSENTIAL COMPONENTS OF A DROUGHT MONITORING AND FORECASTING SYSTEM?

In order to define the components of a drought monitoring and forecasting system it is important to first define what needs to be monitored and forecasted. This can be best understood by defining how to recognize drought. Definitions of drought care given in

Chapter 2 of this document. Drought is closely related to the hydrological cycle. To monitor and forecast drought, one would therefore have to monitor and model the different components of this cycle and these include storage of water in groundwater, soils, rivers, lakes and the atmosphere, as well as the transfer of water through these different stores: precipitation, evapotranspiration, runoff etc. Wind and irradiation might affect the spatial distribution of rain and other processes, again affecting the hydrologic cycle and therefore potential drought. Vegetation also forms a water store, but more importantly, it is a proxy to know more about the soil water condition. A proxy is an indicator or an indirect measure for something else. Observing vegetation might therefore give indications of potential drought in agricultural contexts. Similarly, it is interesting to consider that drought may propagate through the hydrological cycle and that monitoring one type of drought may give indications of drought risks further on in the cycle. Some of the parameters that can be used to monitor an forecast drought are listed in **Table 1**.

Table 1: Parameters to monitor for different types of drought

Drought Type	Parameters to monitor and forecast
Drought	Precipitation
Meteorological	Precipitation, potential evapotranspiration, wind speed and direction
Hydrological	River runoff, reservoir water levels, depth of snow
Agricultural	Soil moisture, vegetation
Socio-economical	Weather-related shortfall in water supply, forage, food grains, fish, and hydroelectric power (economic goods and services); people interactions, health and quality of life (lives of people). Population numbers, household income, economic indicators such as GDP.

The difficulty in recognizing drought is that not every period where the parameter e.g. precipitation is lower than normally will result in a drought event. The drought history and the duration of the deficit are of influence too. Therefore simply defining a threshold for each of the parameters mentioned in the previous paragraph will not be sufficient. A more complex methodology is required that “can select drought events from the remainder of the meteorological or hydrological time series”. Based on this hydrological series, one would have to define what is normal and what is not normal. The current WMO procedure applies the average over the past 30 years ending with “0” as “normal” for example 1981 - 2010. This means that “normal” is constantly updated.

A drought event can be described by its **duration** (or 'run length') and the **drought volume** ('run-sum'), which is an indication of severity. The **drought intensity or severity**, finally, is the ratio between deficit volume and deficit duration (V/t). A spatial aspect should be added, because the **place** where the drought occurs is also important and the **extent** of the affected area. A severe drought which occurs only in a very small area may be of less significance that a less severe drought which affects a much larger area. A drought monitoring and forecasting system should be able to provide information on the duration, severity and spatial spread of a drought.

This section describes the flow of data in a with "state-of-the-art" monitoring and forecasting system. This involves four main steps namely (a) monitoring of drought parameters (b) managing data, (c) processing data and (d) making information available to the public.

3.3.1 How drought is monitored

Monitoring of drought is done either in-situ or using satellite technology. In the US **in-situ drought monitoring** is done by institutes like the Bureau of Reclamation, the USGS, NRCS and the Army Corps of Engineers. They use stream gauges and weather stations at their facilities. Soil moisture can also be measured in-situ. The NDMC collects impact reports from observes who are located in their local environment.

Satellite-based drought monitoring is conducted by NASA and NOAA. AVHRR from NOAA is useful for monitoring vegetation and several products like MODIS and GRACE from NASA are useful for monitoring the hydrologic cycle. MODIS shows surface water, while GRACE shows changes in the gravity field of the earth which can be used to derive changes in groundwater storage using complex computations. Land cover products are also important in drought monitoring and forecasting, as well as elevation information, like SRTM. Land cover and land use are important for more socio-economic factors, but can also be used for detecting changes terrain-roughness, elevation or slope, which are important for estimation of runoff. Satellite imagery can be used to observe fires and their spread, which are often related to dry conditions. Land surface temperature can also be obtained from satellite imagery, notably from the Advanced Along Track Scanner Radiometer (AATSR)

3.3.2 How data is managed

The flow of data **from observation networks to databases** is often automated. Networks send in-situ measurements regularly to a database via the internet or satellites. Often this data will first be checked by the responsible institute, to remove outliers for example. Similarly, satellite imagery is sent to Earth at regular intervals, after which either the raw data or processed data becomes available to the public. Due to checking and post-processing, a lag time may exist between measurement and delivery to public (or private) databases. NOAA CPC receives data via a dial-in system form first- and second-order reporting stations. These stations are operated by the Federal Aviation Administration and military installations.

Once the data is checked and available in public and private databases, other institutes might access the data. To obtain data from the **databases to institutional servers requires** certain technology. The type of technology applied depends on institutional preferences but there is now a move towards web-based technology. Some databases have insider information for example the Delft-FEWS as applied in the USGS and NWS. The Australian AWAP project described in **Appendix A** fact sheet No ND N 04 provides a clear example of the infrastructure for data processing. Some data from monitoring networks and databases is also available in the public domain and for this official partnerships or agreements are necessary. However, it is not advisable to rely on a certain service for operational monitoring and forecasting without an explicit agreement. Without this agreement, changes in data delivery might occur, without the knowledge of institutions down the line and this could disrupt the regular process of monitoring and forecasting. Public web-data access can be anonymous and non-public requires a login file transfer protocol (FTP). Many programming languages, programs and frameworks are capable of making FTP connections and thus downloading or uploading data from one server to another, or to a local machine. The AWAP described in in **Appendix A** fact sheet No ND N 04 states that "*Perl scripts are used to integrate programs, pull data from network servers, log run parameters and anomalies, archive outputs and push results to the presentation server. A standardised, automated directory structure is used to manage inputs, outputs, archival and documentation."* Perl is only one of many different programming languages available that can do this. The same thing would be possible using Python, C and other languages. There are also systems **like** Delft-FEWS which are developed specifically for managing data and data flows among distributed servers. Delft-FEWS is used at the USGS (SWMM model for urban Rainfall-Runoff) and at NWS for a number of hydrologic models.

To manage geodata on online servers, the commercial product ArcGIS server from **ESRI** is an option (http://www.esri.com/software/arcgis/arcgisserver/index.html), but open source options are also available. **Geoserver**, for example is an open source Java server designed for sharing and editing geospatial data.

What these different systems have in common is an ability to get data from and put data into remote or local locations. They are able to work with many different data formats and they use web standards, assuring that other applications are able to 'continue' working with the data. They provide the following services: **Web Feature Service (WFS)** and **Web Coverage**

Service (WCS) standards, as well as a high performance certified compliant **Web Map Service (WMS)**. **GeoServer** is the reference implementation of the Open Geospatial Consortium (OGC) and forms a core component of the **Geospatial Web**. **WMS** publishes maps by creating maps on the server and then sending them as images. **WFS** is a format to serve polygon-information. **KML** is an xml format developed by Google. **NetCDF** is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data.

Innovative tools and mechanisms for data management and transfer are being developed in Australia's WIRADA alliance described in **Appendix A** fact sheet No DM N 05. In this Alliance the Bureau for Meteorology and CSIRO collaborate to improve Australia's technical infrastructure for data management. The alliance comprises several interesting research tracts, for example the hydrologists work bench – aimed at automating workflow processes to access, calibrate and use hydrological models and data; and the Water Data Transfer Standards project – which develops standard interfaces and encodings to access data.

Institutions can use these standards, systems and programming languages to access data and to store it in their own online or offline databases, after which their own models can access it and make runs for forecasting, or can post-process the data for informative visualisation.

3.3.3 How data is processed

Data is processed using **models and GIS tools**. The data formats, resolution and time-step are important considerations. Data is processed to produce several indices which are then used for monitoring and forecasting drought. For monitoring, the indices are calculated with observed data. For forecasting, models are used to produce the data with which the index can be calculated. Institutions have a choice on models to use and they also generate different indices. The following indices are among the common ones calculated:

- Standardized Precipitation Index (SPI) see **Appendix A** factsheets Nos. DM N 08, 09 and 10)
- Palmer Drought Severity Index (PDSI) see **Appendix A** factsheet No. DM N 08
- Keetch-Byram Drought Index
- Surface Water Supply Index (SWSI) see **Appendix A** factsheet No. DM N 11
- Crop Moisture Index (CMI) see **Appendix A** factsheet No. DM N 08
- Normalized Difference Vegetation Index (NDVI) (VH and VegDRI are described in **Appendix A** factsheets Nos.DM N 09 and 15

The following models are used:

- VIC model see **Appendix A** factsheet No. DM N 16
- NLDAS model see **Appendix A** factsheet No. DM N 08
- Leaky Bucket Model see **Appendix A** factsheet No. DM N 08
- WaterDyn model see **Appendix A** factsheet No. DM N 04

The following algorithms are applied:

- Australian National University 3-D spline surface fitting algorithm in AWAP see **Appendix A** factsheet No. DM N 04
- Cressman objective analysis for SPI see **Appendix A** factsheet No. DM N 10

On **formats,** the CPC Leaky Bucket Model is written in FORTRAN, a programming language commonly used at universities and research institutes. **GIS Programs** used include GrADS and ESRI ArcGIS. There is a stand-alone program available to calculate SPI (see **Appendix A** factsheet No DM N 10). Data formats used include NetCDF, ASCII grids, ESRI grids and GRIBS file-types.CSV is often used to provide tabular data, or per-station-data. More general files use gif and pdf formats while gif and .png are often produced by WMS services. The Bureau of Meteorology (BOM) provides metadata in pdf format, complying to ANZLI C metadata profile v1.1. ESRI provides the option to add meta-data in xml-files that accompany files.

On **resolution of data,** BOM and SILO provide gridded weather data at 0.05 degree. Observed data in Australia allows an accuracy of 0.01 degrees (approximately 1km). NLDAS is used at 1/8 degree (14 km in North America. AVHRR products often have a resolution of 4km.The NDVI and other vegetation indices use **satellite imagery**. In the US the RangeView website http://rangeview.arizona.edu/ provides applications for viewing, animating, and analyzing satellite imagery in order to monitor vegetation dynamics through time and across landscapes. RangeView is described as simple to use and valuable for natural resource managers, land owners, educators, and researchers. RangeView provides tutorials and tools to get started with Satellite imagery. The viewers and products however are no longer updated. The viewers show AVHRR NDVI products from 1989 to 2008 and MODIS NDVI products from 2000 to 2006.

Monitoring and forecasting products are often produced at several time intervals. The smallest and most recent interval is real-time information. But this is not always possible or relevant. Climate data is often provided in **near-real time** or at daily intervals. The smallest time-interval for the delivery of Drought information is often weekly. Monitoring information will often provide averages for the past week, 2 weeks, month, season, half year, year, 2 or 3 years. Forecasting efforts will often use the same time-frames to look into the future. Some institutions warn that there is a lot of uncertainty when trying to forecast future drought if that future is more than 3 weeks away.

3.3.4 How information is made available to the public

Information is made available to the public and policy makers as views, which vary in complexity form from simple to sophisticated. Some often-used OGC standards for geodata are available from the internet. Information is shared through web-browsers and so-called geoweb applications. These capabilities can often be obtained together with the server-technology used, but this is not always necessary, because most servers can deliver data in the formats and standards the user desires. WFS, WMS, WCS, KML and NetCDF are all OGC standards that most geo-servers can work with. ESRI for example provides some geoweb applications for use in conjunction with their server, but these obtain their data in the same way as other open source webmap applications would. ESRI's servers are also capable of producing streams of data, for example in JSON, AJAX, Python, PHP, Java script or active-script. These formats can be used in conjunction with other web-languages. Other servers are probably capable of the same thing.

Although all viewers provide access to maps and data, they are all quite different and may have interesting different features. For example, NOAA sometimes simply gives links to CSV files, which can be linked to a geographic extent by a code. The HPRCC provides a 'permanent'-link and uses GET-capabilities to select and serve the right map.

More sophisticated visually attractive and interactive websites developed for internet have led to new technologies. Technologies as JSON, AJAX, Python, PHP, Java script, active-script and flash are now available to the web developer who wants to serve geo-data. Geodata often involves a lot of different datasets and layers which may need to be shown. For this, GIS is applied at it allows showing of several layers overlapping each-other and this is therefore often desired in a web viewer. An often used and very effective way of serving maps via the internet is simply to link to 'flat' images and to provide a web form to select the correct image. Flat images may contain several layers of information, like titles, the drought index, state boundaries and a legend, flattened into a single image. This is a simple and effective way which doesn't require a complex infrastructure. It is likely that these images are produced by a FORTRAN script or other system that produces the monitoring and forecasting data, and are automatically placed on the web server, for example by FTP.

At the other end of the spectrum are complex, sophisticated viewers that take in data streams and create viewers, which serve their data in separate layers, allowing users to toggle layer visibility, zoom in and out etc. Data can be recombined by adding or removing layers and zooming in and simultaneous ‘drilling down’ through different data sets (i.e. from course resolution to local, high-resolution results from a different model-run) is possible.

Print-screens of the web-viewer used by the different institutions to publish their climate-and drought-data are included in the factsheets in **Appendix A**.

4 INVENTORY OF GLOBALLY AVAILABLE STATE-OF-THE-ART DROUGHT MONITORING AND FORECASTING SYSTEMS

4.1 DROUGHT MONITORING AND FORECASTING IN THE UNITED STATES OF AMERICA (USA)

The most important institutions involved in drought monitoring and forecasting in the U.S.A. are as follows:

- The NDMC – National Drought Mitigation Center
- Several National Oceanic and Atmospheric Administration (NOAA) institutes, most notably the NOAA Climate Prediction Center, the NOAA – National Environmental Satellite Data and Information Service (NESDIS), the NOAA National Climatic Data Center and the NOAA - National Weather Service (NEWS).
- Other NOAA departments of interest are; NOAA – NOHRSC, NOAA – River Forecast Centers and NOAA - NWS – EMC – Environmental Modelling Center
- Other institutes notably
  - NRCS - U.S.A. Department of Agriculture, Natural Resources Conservation Service
  - USGS WaterWatch
  - HPRCC – the High Plains Regional Climate Center
  - Bureau of Reclamation
  - Army Corps of Engineers
  - National Weather Service
  - NASA

and the following universities:

- University of Washington
- Princeton University
- University of Arizona
- Columbia University

The factsheets and detailed descriptions of the institutions are provided in **Appendix A**. **Table 2** shows the institutes provide access to measured data. This is disclosed through databases. The names of the databases are given in brackets, for example in the case of SNOTEL RS indicates a Remote-Sensing product.

Table 2: Types of data collected by different institutions

Type of data collected	Name of Institution						
	USGS (Water Watch)	Bureau of reclamation	Army Corps of Engineers	watermonitor.gov	NRCS	NOAA - NWS	NOAA – NCDC
Precipitation					Y - PRISM	Y	Y – ACIS
Temperature					Y	Y	Y – ACIS
Stream flow	Y	Y	Y	Y		Y	
Flood	Y					Y	
Drought	Y		Y				Y
Fire						Y	
Runoff	Y					Y	
Reservoir		Y	Y	Y			
Groundwater				Y	Y – SCAN		
Snow				Y - SNOTEL	Y - SNOTEL	Y - NOHRSC	
Water supply					y		

The most important products/systems from the US are already available for Africa. They are presented and discussed in Deliverable D2.1 and can be summarised as follows:

1. the US Drought Monitor[1] (Factsheet DM G 05)
2. the North American Drought Montior (Factsheet DM G 06)
3. the US Drought Outlook (Factsheet DM G 08)
4. the Drought Impact Reporter[2](Factsheet DM G 07)

Apart of the above products, the following indices and parameters are produced in near-real-time by different institutes: Precipitation and the Standardized Precipitation Index (SPI), the Palmer Drought Severity Index (PDSI), the Keetch-Byram Drought Index, the Surface Water Supply Index, the Crop Moisture Index, Soil Moisture, VegDRI and other Vegetation health indicators, Snow and monitoring and forecasting of fire.

Table 3 shows products, indices and parameters produced by different institutions.

Table 3: Products, indices and parameter produced by different institutions

Theme	O/I/ RS	Product/ Index/ Parameter	USDA	NDMC	NOAA-NWS/CPC	NOAA-NCDC	NOAA-other	NRCS	HPRCC	ASFS	NASA	USGS	University of Washington	University of Texas	University of Princeton
Drought	O	**US Drought Monitor**	Y	Y	Y										
Drought	O	**North American Drought Monitor**				Y									
Drought	I	**Keetch-Byram**								Y				Y	
Drought	I	**Palmer Index**		Y	Y	Palmer Drought Model									
Precipitation	I	**SPI**		Y	Seasonal Drought outlook, temp.& precip, dynamic models	Y			Y						
Hydrologic	I	**Surface Water Supply Index**						Y					Forecasts		
Agriculture	I	**Crop Moisture**			Y	Y	National Water Resources Outlook								
Soil	I	**Soil Moisture**			Cchange in SM, PDSI outlook, GFS, CAS models, leaky Bucket model		NLDAS	SCAN			NLDAS		Exp. Surface Water Monitor, Variable Infiltration Capacity Macro-scale Hydrological Model.		Exp. Soil Moisture Forecasts (ESP & CFS)
Vegetation	RS	**Veg &VegDRI**	Y	Y				Y	Y			Y			

Where P = Outlook-type product, I = Index-type product, RS = Remote Sensing-based product

4.2 DROUGHT MONITORING AND FORECASTING IN AUSTRALIA

Until recently, water information in Australia was held by hundreds of different institutes. Now a unified system is being adopted and hundreds of institutes are now required by law to provide their water information to the Bureau of Meteorology (BOM). CSIRO is helping BOM to improve the data management processes and data products that can be produced will all this data. Drought monitoring and forecasting in Australia is done by a few institutions. The BOM and CSIRO are the most important ones. The factsheets and detailed descriptions of the institutions are provided in **Appendix A**. Through the AWAP project and the WIRADI alliance, these institutes are collaborating to improve the water monitoring, forecasting and management capacities in Australia. One of the objectives of this alliance and partnership is to develop a highly sophisticated, "state-of-the-art" water monitoring and forecasting system. This should be a single, automated system, which takes and places data on distributed servers, and processes data to relevant products. The system is still under construction, but operational parts of it are already being released. The system is also very well described, offering a good insight of what a state-of-the-art drought monitoring system would consist of, in terms of data flows, processes and technologies.

4.3 DROUGHT MONITORING AND FORECASTING IN EUROPE

The monitoring and forecasting systems networks/institutions in Europe identified on this study are listed in **Table 4** and

Table 5. Each system/network forum is assigned an identification number for easy referencing. The factsheets and detailed descriptions of the networks/institutions are provided in **Appendix B**.

Table 4: Products, indices and parameter produced by different institutions

ID	Location	Name	What is it?	Website	Coverage	Contact Details
			Europe			
DM N 01	Europe	European Drought Observatory (EU)	Network, System	http://edo.jrc.ec.europa.eu	Europe – Continental, Regional	Jürgen Vogt Phone: (+39) 0332 785481 Email:juergen.vogt(at)jrc.ec.europa.eu
DM N 02	Europe	Drought Management Centre for South-Eastern Europe (DMCSEE)	Network, System	http://www.dmcsee.org	Regional	Environmental Agency of the Republic of Slovenia Meteorological Office Vojkova 1b 1000 Ljubljana Slovenia Tel.: +386 1 478 40 00 Fax: +386 1 478 40 54 Project coordinator: Gregor Gregorič Email: gregor.gregoric@gov.si
DM N 03	Spain	Hydrological drought evaluation system – Spain	System	http://servicios2.marm.es/sia/indicadores/home.jsp	National	Ministerio de Medio Ambiente y Medio Rural y Marino. Plaza de San Juan de la Cruz s/n 28071
DM N 04	Portugal	Drought Observatory (Observatório de secas – Instituto de Meteorologia)	System	http://www.meteo.pt/pt/oclima/observatoriosecas/	National	Rua C do Aeroporto 1749-077 Lisboa, Portugal Telefone (351) 218 447 000 Fax (351) 218 402 370 Email: informacoes@meteo.pt
DM N 05	Portugal	System of Prediction and Management of Droughts (Sistema de Previsão e Gestão de Secas) – Portugal	System	http://www.spgs.tk/	National	
DM N 06	Italy	The drought bulletin - ispra – istitutosuperiore per la protezione e la ricercaambientale)	System	http://www.isprambiente.gov.it/pre_meteo/siccitas/index_en.html	National	Via Vitaliano Brancati 48 - 00144 ROMA Tel. (+39) 0650071 Fax (+39) 0650072916
DM N 07	United Kingdom	Drought evaluation - Environment Agency	System	http://www.environment-agency.gov.uk/homeandleisure/drought/default.aspx	National	National Customer Contact Centre PO Box 544 Rotherham S60 1BY Email:enquiries@environment-

ID	Location	Name	What is it?	Website	Coverage	Contact Details
						agency.gov.uk
DM N 08	United Kingdom of Great Britain	Water and Global Change (WATCH)	Network, System	http://www.eu-watch.org/	Global	Dr. Tanya A. Warnaars Centre for ecology & Hydrology. Maclean Building, Wallingford. Oxfordshire, OX10 8BB, United Kingdom info-watch@ceh.ac.uk
DM N 09	Italy	XEROCHORE	Network	http://www.feem-project.net/xerochore/index.php	Europe, Northern Africa	Anil Markandya, FondazioneEni Enrico Mattei (FEEM), Italy. Email: xerochore@feem.it
DM N 10	Spain	Mediterranean drought Preparedness Plan (MEDROPLAN)	Network	http://www.iamz.ciheam.org/medroplan/	Europe, Northern Africa	Dunixi Gabiña Mediterranean Agronomic Institute of Zaragoza (CIHEAM-IAMZ), Spain Apartado 202, 50080 Zaragoza. Spain Tel: +34 976 716000 Fax: +34 976 716001 Email:iamz@iamz.ciheam.org

Table 5: Research and development projects

ID	Name	Coverage
DM P01	**ACQWA** Assessing Climate Impacts on the Quantity and Quality of Water	**Mountain Regions:** - Europeans Alpes, - Pyrenees - Aconcagua Basin - Chile- Kyrgystan – Asia
DM P 02	**ADAM** Adaptation and Mitigation Strategies	- Guadiana Basin – Spain & Portugal - Inner Mongolia - Cjina - Tisza River Basin – Hungary
DM P 03	**AquaStress**	- Flumendosa - Mulargia (Italy) - Guadiana (Portugal) - Vecht (Netherlands), - Przemsza (Poland), - Iskar (Bulgaria) - Merguellil (Tunisia) - Tadla irrigation (Morocco) - Limassol (Cyprus)
DM P 04	**ARIDE:** (Assessment of the Regional Impacts of Droughts in Europe)	**- Europe**
DM P 05	**BALANCE**	- Barents Region
DM P 06	**Cabri Volga**	- Volga Basin (Russia)
DM P 07	**CECILIA:** Central and Eastern Europe Climate Change Impact and Vulnerability Assessment	**- Central and Eastern Europe.**
DM P 08	**Circe:** A changing climate, an adaptation world	- **North Africa** (Algeria, Tunisia and Egypt) - **Middle Eastern** (Israel, Lebanon and Syria) - **Europe** (Spain, Italy and Greece)
DM P 09	**CLICO:** Climate Change Hydro-conflicts and Human Security	- **Mediterranean area** - Niger, - Sudan, - Ethiopia, Marocco - Spain, Italy ,- Turkey, - Jordan - Egypt.
DM P 10	**CLIMB:** Climate Induced Changes on the Hydrology of Mediterranean Basins	- **Mediterranean area** Egypt, Gaza, France, Italy Tunisie
DM P 11	**DMCSEE Project:** Drought Management Center for Southeastern Europe	**- Southeastern Europe:** Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Former Yugoslav Republic of Macedonia, Greece, Hungary, Moldova, Romania, Slovenia, Turkey, Montenegro and Serbia
DM P 12	**Drought R&SPI:** Fostering European Drought Research and Science-Policy Interfacing	**Southern Europe:** - Po River Basin – Italy - Netherlands, Jucar River Basin – Spain - Syros Island of the Cyclades complex – Greece, Portugal,- Switzerland
DM P 13	**ENSEMBLES:** Climate Change and Its Impacts	- Rhine Basin - Alps, Castillas Leon – Spain - North Sea, Andalucia - Spain - Scandinavian forests, Romania - Danube Basin, North Italy
DM P 14	**EU Watch:** Water and Global Change	**- River basins:** Amazonas; Nile; Mississippi; Paranha; Lena; Niger; ChiangJiang; Mackenzie; Ganges-Brahmaputra; Volg; Indus; Murray-Darling; Orange; HuangHe; Danube; Rhine; Mekong; Congo
DM P 15	**Glowa Danube:** Global Change in the Hydrological Cycle	**Europe:** - Danube Basin,- Elbe Basin **Africa:**- Draa (Morocoo),- Queme (Benin) Volta (West African savanna zone) **Middle East:**- Jordan
DM P 16	**HYACINTS:** Hydrological Modeling for Assessing Climate Change Impacts at different Scales	- Denmark
DM P 17	**HyMex:** Hydrological cycle in Mediterranean Experiment	- North-Western Mediterranean, South-Eastern Mediterranean , The Adriatic

ID	Name	Coverage
DM P 18	**MedClivar:** Mediterranean Climate Variability and Predictability	**- Mediterranean Zone**
DM P 19	**MEDROPLAN:** Mediterranean Drought Preparedness and Mitigation Planning	**- Mediterranean Zone:** Marocco, Spain, Tunisie, Italy, Greece, Cyprus
DM P 20	**NeWater**	- Rhine (North Europe), Elbe (North Europe), Guadiana (Spain/Portugal) - Tisza (East Europe), Amudarya (central Asia), Nile (North Africa) - Orange (south Africa)
DM P 21	**PRUDENCE:** Prediction of Regional scenarios and Uncertainties for Defining European Climate change risks and Effects	- Europe
DM P 22	**SCENES:** Water Scenarios for Europe and for Neighboring States	- Baltic, Mediterranian, Lower Danube, and Black Sea. There are 10 Pilot areas: Lake Peipsi, Narew, Lower Don, Crimea, Danube Delta, Tisza, Candeliaro, Garonne, Guadianna, Seyhan.
DM P 23	**SIAM & SIAM II:** Climate Change in Portugal: Scenarios, impacts, and adaptation measures	**- Portugal**
DM P 24	**SicMed:** Surfaces et Interfaces Continentales en Méditerranée	**- Mediterranean Zone**
DM P 25	**WAM-ME:** Water Resources Management Under Drought Conditions: Criteria and Tools for Conjunctive Use of Conventional and Marginal Waters in Mediterranean Regions	**- Mediterranean Region**
	WASSRMED: Water Availability and Security in Southern Europe and the Mediterranean	**- Mediterranean Zone:** Greece, Italy, Tunisie and Egypt

5 WHO ARE THE USERS OF EXISTING DROUGHT MONITORING AND FORECASTING SYSTEMS IN AFRICA?

5.1 NORTH AFRICA – ALGERIA, MOROCCO AND TUNISIA (MAGHREB REGION)

This section relies on deliverable D2.3, which assesses drought warning experiences in Africa with a focus on Morocco. The focus on user's requirements is also on Morocco.

In Morocco, the main users of existing drought monitoring and forecasting systems are:

- Crop and livestock producers;
- Ffarm organizations;
- Aagribusinesses;
- Regional and national farm policy makers;
- Government agencies;
- Research institutions.

5.2 EQUATORIAL LAKES REGION

5.2.1 Tanzania

The users of drought monitoring and forecasting systems in Tanzania include;

- Meteorological offices or agencies
- Early warning systems organisations or offices
- Disaster management organisations or offices
- General public (farmers, pastoralists, traders, etc.)
- International agencies (FAO, UNICEF, NGOs, etc.)

5.2.2 Kenya

The users of drought monitoring and forecasting systems in the Kenya include;

- National government agencies responsible for resource planning and emergency interventions for droughts and floods
- Government and non-government agencies in sector development planning and implementation
- The general citizenry for their empowerment and capacity building for climatic disaster resilience.

5.2.3 Rwanda and Burundi

The users of drought monitoring and forecasting systems in Rwanda and Burundi are as follows:

- Farmers (people)
- Various research institutes and universities
- Policymakers (various ministries and their authorities).

5.3 EASTERN NILE REGION (ETHIOPIAN PLATEAU)

The users of drought monitoring and forecasting systems in the Eastern Nile Region are as follows:

- line ministries and humanitarian agencies
- government, donors and the international community.
- local government officials
- the federal level, and Woreda officials
- Early Warning response directorate(EWRD)
- Save the Children UK
- Household Economy Approach (HEA)
- FAO
- DPPC's Early Warning Working Group
- IGAD Climate Prediction and Applications Centre (ICPAC)
- Humanitarian Early Warning Service (HEWS)
- farmers, herders

5.4 EASTERN NILE REGION (DOWNSTREAM COUNTRIES)

5.4.1 Users of information - Egypt

Based on the prediction of the Nile flow the MWRI has constructed a ministering committee for managing the river flow, it includes the following sectors:

- Nile Water Sector
- High Aswan Authority
- Water Management and Distribution Sector
- Irrigation Sector sub-Sectors
- Development Irrigation and Nile protection Sector

5.4.2 Sudan

The Sudan Meteorological Authority and Ministry of Irrigation and Water Resources provide advice to policy makers in all issues about climate and weather and provide data and information for public use, scientific research and farmers. Data and information are also provided to the following:

- The Council of Ministers
- Ministry of Irrigation and Water resources
- Ministry of Agriculture
- Ministry of Humanitarians Affairs
- Ministry of Animal Resources

Meteorological information is collected hourly using a 34 observing station network and recently there are number of automatic weather stations. The Meteorological Authority is also consulted by some organizations and companies.

5.5 SOUTHERN AFRICA

Table 6 lists the direct users of drought warnings identified on this study.

Table 6: List of direct users of drought warnings

Stakeholders and Interest Groups	Interpretation of warnings	Particular interest
Department of Water Affairs	Use of El Nino and La Nina, also the historical dam inflow data and water allocation relative to the dam level	Dam Management
Department of Agriculture	Seasonal forecast issued by South African Weather Services for the below normal to above normal rainfall	Drought Management
Municipalities	Warnings are given by the department of water affairs for any availability of water	Water Distribution
Catchment Management Areas	No warnings issued	Water Management
Water Users Association	Some application of self-restrictions is applied by some water users or practice physical observation of stream	Water Availability
Disaster Management Centres	Seasonal forecast issued by South African Weather Services for the below normal to above normal rainfall	Drought Management

5.5.1 South Africa

The main users of drought early warnings are shown in **Table 7**.

Table 7: Main users of drought early warnings South Africa

Stakeholders and Interest Groups	Interpretation and Use of Warnings
Department of Water Affairs	Use of El Nino and La Nina, also the historical dam inflow data and allocate water considering dam level and available yield
Department of Agriculture	Seasonal forecast issued by South African Weather Services for the below normal to above normal rainfall
Municipalities	Warnings are given by the Department of Water Affairs on availability of water
Catchment Management Areas	No warnings issued
Water Users Association	Some application of self-restrictions is applied by some water users or practice physical observation of stream

Stakeholders and Interest Groups	Interpretation and Use of Warnings
Disaster Management Centres	Seasonal forecast issued by South African Weather Services for the below normal to above normal rainfall
Food and Nutrition Council.	Nutritional status of infants and other people
Parliamentary Portfolio, Committee on Lands, Agriculture, Water Development, Rural Resources and Resettlement, President's Office,	Timing of declaration of the drought. Mobilising funding Appealing for funding

In order to inform the formulation of this report we held meetings with farmers/stakeholders to capture their requirements for early warning. The following is a summary of their requirements:

- Lead time for planting period 3-5 months
- Single source with reliable data (with information on success rate of forecasts, provide evidence from history)
- Predictions at local scale (maps which show forecasts for whole of Limpopo are not useful). Forecasts should zoom to areas which users can relate to
- Spatial scale for predictions which considers variability of rainfall
- Easy to understand information (communicate risks of forecast clearly to enable users incorporate this information into their own risk management frameworks)
- A tool that that translates the forecast into information on the availability of water in rivers and dams
- System that predicts long term dry periods for estimation of availability of food

5.5.2 Zimbabwe

The main or key users of drought monitoring and forecasting information in Zimbabwe are government agencies, farmers, who form the bulk of users and NGOs.

Table 8 lists the direct users of drought warnings identified on this study.

Table 8: List of direct users of drought warnings

Stakeholders and Interest Groups	Interpretation of warnings	Particular interest
Government Ministries		
Lands, Agriculture & Rural Resettlement: AGRITEX, MSD	Communicating the warning to farmers Interpreting the warning to a product that can be useful to farmers. Offering advice on appropriate methods & ways to tackle the impending situation.	Custody of agricultural policy
Finance and Economic Development.	Costing the extent of drought in monetary terms. Lobbying for aid or funding.	Macro-economic growth and stability
Local Government and National Housing.	Mainly use the information to ensure coordination of drought management.	Civil protection, coordinates government social protection programmes, drought relief and emergencies .Coordinates and

Stakeholders and Interest Groups	Interpretation of warnings	Particular interest
		oversees all local government administration and leadership
Public Service, Labour and Social Welfare	Assessment of community vulnerability levels. Putting in place timely welfare programmes to assist affected communities.	Maintaining welfare and implementation of social safety nets and welfare programmes
Food and Nutrition Council.	nutritional status of infants and other people	Development and monitoring of policies, strategies and programmes for addressing food and nutrition security
Parliamentary Portfolio, Committee on Lands, Agriculture, Water Development, Rural Resources and Resettlement, Presidents Office	Timing of declaration of the drought. Mobilising funding Appealing for funding	The Committee monitors the general performance of the executive (government) and undertakes specific investigations for information of Parliament.
Farmers:		
Small holder farmers	Nature of the season	
Commercial farmers		
Local rural leaders:		
Traditional leaders.	Community governance	
Agribusiness.		
GMB.	Sourcing grain	Acquisition (from local and external sources), storage and distribution of grain to ensure national food security
AGRIBANK.	Funding relief programme	Long-term viability and maximizing dividends
Milling Companies.		
Livestock Feed Processors.		
Seed producers.		
Consumers.		
Both rural and urban communities	Stocking of food reserves	
Media	Ensuring warning is disseminated to the people. Production of progress reports.	Provision of timely and accurate information.
NGO: (Local and International)		
Christian Care, World Vision, Care International, Africare, World Lutheran Federation, ORAP, Plan International, Catholic Relief, Save Children UK, Save Children USA	Preparation and provision of relief. Lobbying for relief fund. Reporting. Carrying out vulnerability assessment	Advancing food security and social well-being of communities Economically empowering local Communities. Securing and maintaining funding from sponsors
International Donors (Development partners):		
USAID, DFID, GTZ, NORAD, AUSAID, Canada CIDA	Provision of relief fund	Promoting poverty reduction at community levels through efficient and effective use of donor resources

5.6 WEST AFRICA – MALI

Table 9 lists the direct users of drought warnings identified on this study.

Table 9: List of direct users of drought warnings

1. **Who uses the information ?**	2. **How information reaches users**	3. **Comment l'information est interprétée (alertes - autochtones et locales)**	4. **What is the response to the assessed information? (provide all available data)**
Farmers, herders, fishermen	Television, Radio	Decision on crop seeding	Prediction of crop calendar
All those involved in fish industry	TV, Weekly magazine of the Regional Directorate of Fisheries	Fishing period	Anticipation of the fishing season
Users are the socio-economic organizations and local communities, NGOs, decentralized services of the state, rural and urban districts	Progress reports, annual reports and a monthly newsletter sent to technical services and they are responsible for transmitting its information to grassroots communities through the extension agents that are on site	The information is interpreted by the technical officers.	This information allows users to take steps to adapt to changes that are planned in their area.
Users (farmers, fishermen, farmers)	Radio, television and telephone	Decision for the planning of activities (period of ploughing period sown, etc.).	Planning of activities
Local communities, Technical Services of the State and NGOs	Radio, television and monthly reports are distributed to the Technical Services	The information is interpreted by the technical officers.	Taking measures to prevent natural disasters

6 USER REQUIREMENTS FOR DROUGHT MONITORING AND FORECASTING IN AFRICA

Figure 3 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".

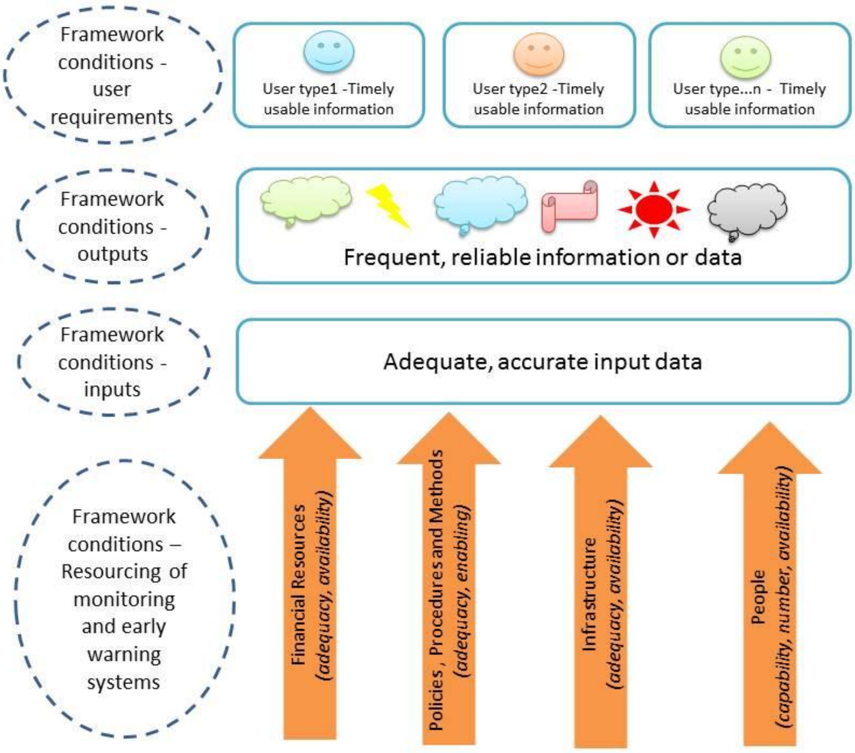

Figure 3: Comparative analysis of monitoring and early warning systems – Framework diagram.

This section presents a summary of the requirements for drought monitoring and forecasting systems for the users (users are described in Chapter 5) as captured in more detailed in Deliverable D2.3.

6.1 NORTH AFRICA – ALGERIA, MOROCCO AND TUNISIA (MAGHREB REGION)

The user requirements for drought monitoring and forecasting systems in this region can be summarised as follows:

- More reliable operational and monitoring information
- Integrated and more objective information.
- More effective institutions involved in drought monitoring and early warning
- Information from early warning systems should be usable and relate to intervention options
- Information from early warning systems should support policy development for poverty and livelihood issues, crop production forecasts and trade policy.
- Information from early warning systems should support government in implementation of developmental priorities.
- Drought monitoring tools and forecasting systems should use seasonal forecasts.
- Information on weather related developments and their effects on crops and livestock
- Drought monitoring systems should be integrated, coupling multiple climate, water and soil parameters and socio-economic indicators to fully characterize drought magnitude, spatial extent and potential impact.

Specific requirements of the main users of drought monitoring and forecasting systems are described in this section.

a) Drought monitoring and early warning at national level,

At the national level, within North Africa, each individual country faces its own exclusive set of challenges for developing an improved drought monitoring system based on its specific natural, social, economic, and political resources. As a result, each country may have to develop their drought monitoring systems differently according to their overall objectives and the information and technical resources that are available to them. However, for the development of an effective monitoring system, all North African countries and international and regional organizations, that are operating in the region, must take the same initial first step, which is a thorough investigation of all available information resources and tools that are available at the national, regional, and continental scales that can be integrated into such a system.

Recent efforts to improve drought monitoring and early warning in many developed countries, such as Australia, the United States and some European countries, have provided new early warning and decision- support tools and methodologies in support of drought preparedness planning and policy development. The lessons learned can be helpful models for developing countries, mainly those in Africa, to follow as they try to reduce the impacts of future droughts.

An effective monitoring, early warning and delivery system should track key drought and water supply indicators and climate-based indices and delivers this information to decision makers. This would allow for the early detection of drought conditions and timely triggering of mitigation and emergency response measures, the main ingredients of a drought preparedness plan.

b) Local drought management committees

Centralised drought management has not been effective. Regional or provincial levels may offer better prospects of success where distinct edapho-climatic conditions are used to institutionalize local drought committees. These local committees should consider a range of rather subjective measures as drought indices, which include the following:

(i) availability of water;
(ii) availability of pasture;
(iii) condition of stock;
(iv) the extent of drought movements of stock to forced sales or slaughter and
(v) quantity of fodder to be introduced.

c) Local and regional drought monitoring and early warning agencies

A comprehensive and integrated approach is needed to observe drought more effectively and provide early warning. The collection of climatic and hydrologic data has been fragmented between many agencies or ministries in all North African countries. In Morocco this is now being done by regional watershed agencies. Indeed, the analysis of climate and water data is most effective when it is coordinated under a single authority. The regional agencies are supposed to analyze data and producing useful end products or decision-support tools to deliver to end users. However, often data are not reported in a timely fashion. To address these constraints the following requirements were identified:

- Data collection processes should be automated to substantially improve the timeliness and reliability of drought monitoring and early warning systems
- The main stakeholders should be involved from the early stages of product development to ensure that the information will serve their varied timing and content needs. A delivery system should reflect the needs of these diverse customers.

- Few users could make use of the information on the internet, there is a need to combine other means, such as extension, print and electronic media delivery

In developed countries, the Internet is becoming the most cost-effective mode to convey information, but it is still inappropriate for the main users in Morocco as in other North African countries.

d) People in rural areas

The livelihoods of most rural populations are reliant on traditional agriculture that is dependent on seasonal rainfall. In this context, agro-meteorological monitoring refers to the continuous assessment of rainfall and agricultural conditions:

(i) the start of a growing season is determined by the arrival of adequate rains. Monitoring of the start of season is critical and provides the first indication of the condition of the agricultural season;

(ii) once the rainy season has fully started, variations in the rainfall amount and distribution will determine the performance of crops, pasture, and other natural vegetation.

The analysis of the timing of the start of the rainy season and the temporal and spatial variation through a region will highlight areas where the growing season is early, on time, or has a late onset. These are very important early indicators of the quality of the agricultural season and hence expected agricultural production.

Well-timed forecasts of a dry or wet planting season may prompt farmers to switch to other crops. A poor grain harvest may affect the feeding activities of cattlemen. At the country level, a regional drought can boost planted areas elsewhere to offset the expected production decline. Government policy makers may adjust farm programs to meet the changing conditions

Continuous monitoring of rainfall amount and distribution coupled with available crop growth models can be used for targeted areas, chosen on the basis of their agronomic importance and/or relevant meteorological events. The data used in this type of monitoring may include rainfall estimates over 10 days, number of rain days, vegetation index, and cumulative rainfall amounts (monthly or quarterly). Rainfall is often monitored using a combination of satellite rainfall estimates and ground measurements of rainfall from national networks.

e) Farmers and decision makers

The following indicators are of a major importance to farmers and decision makers:

(i) Onset-of-rains map, as the information on the onset of the growing season provides a tremendous advantage in planning and managing of agricultural activities;

(ii) Soil Water Index (SWI), as the availability of water in the root zone during the growing season is also important information for agricultural producers and decision makers; and

(iii) Crop Water Requirement Satisfaction Index (WRSI), as in the planning and agricultural managing practices, the crop WRSI assists in making decisions.

6.2 EQUATORIAL LAKES REGION (BURUNDI, KENYA, TANZANIA, RWANDA)

6.2.1 Tanzania

The following requirements were identified for users in Tanzania:

- Farmers: Response plans for the lives of crops and people due to shortage of food and water
- Pastoralists: Response plans for the lives of animals due to shortage of food and water
- Disaster management offices:
  - Communication systems and adequate response plans
  - Requires to provide information that allows individuals and communities to protect their lives and property thereby reducing economic losses and mitigate the number of injuries or deaths from a disaster; relief actions

6.2.2 Kenya

The following requirements were identified for users in Kenya:

- National governments require global indecencies for resource strategic planning and emergency interventions for droughts and floods.
- Government and non-government agencies in sector development planning and implementation generally need specific estimates of maximum, minimum and mean values of climate and hydrological parameters and their variation.
- The general citizenry for their empowerment and capacity building for climatic disaster resilience need seasonal plan and advice for their socio economic activities.

6.2.3 Rwanda and Burundi

Drought monitoring and forecasting in both countries Rwanda and Burundi are still to be strengthened. The following are some of the users requirements:

- Detailed weather and climate information as well as development of climate models appropriate for a good weather and climate monitoring and forecast. This requires a number of inputs including the increase in the number of skilled meteorologists, extension of monitoring station network, appropriate software and other IT equipment, upper air weather station, RADAR weather station, etc.
- More research and knowledge development in the field of weather and climate. This requires more involvement of universities and other research institutes.
- Improvement in dissemination of weather and climate information and their application in various socio-economic activities.

More collaboration among various institutes involved in water sector, weather and climate, land management, agriculture development, health sector, research and education, etc.

6.3 EASTERN NILE REGION (ETHIOPIAN PLATEAU)

Most stakeholders at each level rarely share sectoral information among themselves and any information individually shared without consensus to each level creates competition for recognition and thus undermines timely interventions. Stakeholders that lack part of the information are asked to make decisions on outputs from process they do not understand. In addition they do not understand its context, the way the information was gathered and analyzed. Therefore, early warning information from zonal and regional systems needs to be interpreted within local contexts and utilized in conjunction with district level information to be effective, adapt to local circumstances and to prevent misinterpretation and negative impacts.

There is widespread recognition, among Government and development partners, of the need to develop a more unified, transparent, coordinated, and objective early warning system, that has a system of “checks and balances.” Although more than 30 early warning systems, methodologies, and approaches exist in the country, there is no coordinating framework that brings together the different streams of information into a multi-sectoral early warning system that assesses hazards in, e.g., agriculture, health, nutrition, and natural resources management. There should be one major unified early warning system that assesses multi-sectoral hazards across the country, including monitoring of drought risk, food insecurity, health epidemics, malaria outbreaks, livestock diseases, and market information. This requires the coordination of early warning activities from the community level up to the federal levels, across line Ministries at the federal level, and among the many actors and donors working on early warning issues at the community, regional, and national levels.

There has been some progress toward the development of unified early warning systems. In recent months the US AID-funded FEWS NET and the WFP-funded Vulnerability Analysis Mapping (VAM) have joined forces to generate a unified monthly Early Warning Bulletin. This is a major stride toward streamlining and integrating existing monitoring and early warning systems in Ethiopia. In addition, DMFSS has requested technical assistance from FEWS NET and VAM to help in preparation of monthly reports by Government.

The Government has made a strategic decision to decentralize the early warning system to the woreda level, particularly with regards to slow-onset risks such as drought and food insecurity. Given the importance of data captured and used at the woreda level, DMFSS needs to focus on woreda-level capacity building for monitoring and early warning, along with contingency planning and financing. In the existing system, the key information gathered and potential decision-making is at the woreda level. This allows information gathered at the community level to be used by those at the community level. One potential mechanism for the transfer of information between the community, regional, and national levels is through the Woreda Net system, an initiative to connect the woredas through a network. This system is largely non-functional at present but has the potential to be an important mechanism for information dissemination.

Improved data collection at the local level and a strengthened multi-hazard early warning system require reliable information on climate monitoring. The National Meteorological Agency (NMA) currently has about 1,000 hydro-meteorological stations of various classes located throughout the country. However, information at the local level is seen as unreliable, and not captured in a way that would allow the community itself to use the data for early warning and forecasting, and for planning of crop-livestock systems. There is a need to provide capacity building for better and more reliable climate information at the local level through climate downscaling, expansion of hydro-meteorological stations, and support for new technologies. The NMA is promoting the “Mali model” for community-based climate monitoring whereby climatic data, along with other data (e.g., on vegetation, crops and livestock status, human and animal health and nutrition, water resource availability and quality, environmental indicators, etc) are collected at the community level to help in forecasting and early warning, and also to better understand local conditions. In turn, this information can be used together with agriculture and heath extension agents for planning farming systems and livelihoods that have higher returns, are more resilient to hazards, and are environmentally sustainable.

6.4 EASTERN NILE REGION DOWNSTREAM COUNTRIES (EGYPT AND SUDAN)

6.4.1 User Requirements -Egypt

The users need to obtain better understanding of climate variability, and improved management of its associated risks. This presents a real promise to decision makers seeking to understand how to adapt to climate change. In Egypt the Nile Forecast Center (NFC) has the ability to simulate the consequences of changes in the River system and in the climatologically and hydro-meteorological regime of the Basin. The NFC is developing and using hydrologic models that simulate the complete water balance for the entire Nile Basin. The NFC also determines the optimal reservoir release policies in relation to reservoir inflows and storage levels. The main project output has determined scenarios, assess risks and identify mitigation measures due to variations in the Nile River regime and climate leading to floods, droughts and land use changes in the Nile Basin (upstream and downstream) and integrated its findings in Egypt's national water strategy, planning and operations. This information also supports the MWRI in setting scenarios for risk assessment due to floods, droughts and climate change.

6.4.2 Sudan

User requirements for drought monitoring and forecasting systems in Sudan are as follows:

- Timely dissemination of information to end users in suitable format.
- Establishing and coordination of end user’s network.
- Availability and flow of data on a sustainable basis
- Regional drought monitoring and forecasting plans
- Identification of expected drought events before a drought takes place (which is necessary for the growing season especial in rain-fed agricultural mechanized farms)
- Length of the dry spell (supplementary irrigation may be used)
- Length of the growing season (start and end of the rainy season)
- Nile River flow (peak flow season)

For effective drought monitoring and forecasting there is need to

- Increase the temporal and spatial coverage of the drought forecasting and monitoring system (increase number of the weather stations and rain gauges to cover the whole country)

- Effective communication tools and means to disseminate the forecasting and monitoring messages
- Capacity building for Met staff
- Appropriate equipment and infrastructure (RADAR stations, software, GPS) and access to the remote sensing data
- Better interpretation of the drought forecast models
- To link early warning system, drought, desertification and land degradation assessment and their impact on the livelihood of the local communities
- Dissemination of information to the end users on application of early warning systems, drought and desertification monitoring – evaluation, and strengthening appropriate response mechanisms
- Link the Met product and information to the agriculture research and food security

6.5 SOUTHERN AFRICA – SADC AND THE LIMPOPO BASIN

6.5.1 South Africa

Users in South Africa want more precise information to inform the actions shown in **Table 10**.

Table 10: User requirements for early warnings on availability and timing of rainfall

Water User	Associated actions
Rain-fed crop producers	**Soil choice** o Choose suitable soil type. o Roughen the soil surface to minimize evaporation. o Minimize compaction by reducing the passing of heavy machinery in the field. Land preparation: o Avoid, where possible, soils with pronounced plough pans. o Use a ripper to break plough pans and increase access of roots to stored water and nutrients. o Do not expand land under crop production unnecessarily. o Prioritise fallow land.
	Crop choice and planting o Choose drought resistant cultivars or drought tolerant crops as a precautionary measure. o Provide flexibility and diversification. o Stick to normal planting window if appropriate and follow the weather and climate forecast regularly. o Consider staggered planting-spreading over weeks. o Do not experiment with new and unknown cultivars and also avoid unnecessary capital investments. o Always practice crop rotation. o Planting in a controlled environment (e.g. green house) is advisable where possible.
	Crop management o Adjust planting density accordingly. o Consider mulching to minimize evaporation. o Control weeds regularly. o Consider a conservative fertilizing strategy during dry conditions. o Consider organic fertilization. o Scout for pests and diseases regularly and control where

Water User	Associated actions
	necessary
	o Prepare their farming inputs in readiness to plough and plant o Harvest from previous season is preserved Wild fruits and vegetables are also collected and preserved
Irrigation farmers	o Remove all weeds containing seeds, but keep other vegetative rests on the land because that will reduce evaporation. o Check and repair all tools and machinery. o Irrigate during cool conditions to avoid evapotranspiration. o Avoid over irrigation because that can create problems e.g. water logging and diseases. o Adhere to the water restrictions when issued.
Domestic and home garden water users	o Conserve existing water supplies. o Eradicate water weeds. o Limit water waste and losses. o Repair leaking pipes. o Re-use water and retain high quality. o Harvest water during rainy days.
Stock farmers	o Provide lots of drinking points. o Provide phosphorous licks freely. o If grazing is in danger, herd animals into pens where different animals can be segregated and fed separately. o Herd management should be aimed at maximizing animal condition during the growing season as it affects the degree at which animals lose/gain weight and condition during the dry periods. o Decide in advance when to switch the animals to different levels of feeding. o Sell mature livestock as soon as they reach marketable condition. o Treat the rangeland as a valuable asset. o Build fodder reserves in years of good rainfall. o Always practice rotational grazing. o Retain nucleus of best cows aged 4 to 6 years. o Diseases- Local veterinary services. o Always consider relevant vaccinations and control outbreak of diseases.
	Veld and water management o Subdivide your grazing area into camps of homogeneous units (in terms of species. Composition, slope, aspect, rainfall, temperature, soil and other factors) to minimize area selective grazing as well as to provide for the application of animal management and veld management practices such as resting and burning. o Determine the carrying capacity of different plant associations. o Calculate the stocking rate of each, and then decide the best ratios of large and small animals, and of grazers or browsers. o Provide periodic full growing-season rests (in certain grazing areas) to allow veld vigor recovery in order to maintain veld productivity at a high level as well as to maintain the vigor of the preferred species. o Rested veld forms an important source of cheap feed during winter for dry stock with appropriate protein supplementation. o Do not overstock at any time. o Eradicate invader plants. o Periodically reassess the grazing and feed available for the next few months, and start planning in advance. o Spread water points evenly. o Cut forage early to stimulate re-growth. o Provide suitable licks to make coarse, dry range grasses more palatable

These are broad guidelines and interpretation should consider the local aspects of the region such as soil types, cultural preferences and farming systems.

6.5.2 Zimbabwe

The requirements of users in Zimbabwe taken from historical drought experiences are described in this section.

(a) Farmers

The Commercial Farmers' Union (CFU) had been monitoring the media reports of a growing El Niño from the beginning, and so made a special effort to meet with forecasters from the Meteorological Services Department in Harare to discuss implications, and to keep its members knowledgeable. During the winter months of July and August 1997, the CFU incorporated discussions of El Niño into its "field-day" activities in the different regions, reinforcing the probabilistic nature of the prediction. Occurring in July and August 1997, these deliberately coincided with times at which commercial farmers were buying their seed for the upcoming season. The general advice the CFU developed for its farmers, in coordination with the Meteorological Services Department in Harare, was to plant early to take advantage of the predicted good early season rains, and to plant short-season varieties to avoid the likely late season drought. Farmers working with CFU agronomists at the field-day meetings generated location-specific recommendations about what particular varieties to plant. Most farmers incorporated these recommendations into their planting decisions. Using the information was more difficult in the smallholder sector, especially among communal land farmers in drier regions of the country, where "below-normal" rainfall implied a high likelihood of crop failure. Modelling results (Phillips et al 2001), and more recently, field studies (Patt et al 2005), show that the forecasts can be of value to farmers, by allowing them to optimize for the expected rainfall with a different mix of seed varieties and a staggered planting schedule.

As of 1997, except for a few people within NEWU, most people had little idea what ENSO was, and how to interpret the seasonal forecasts. In July1997, Agritex organized a two-day workshop in Harare to discuss the use of seasonal forecasts with Meteorological Services Department and RRSP personnel. One suggestion was to educate Agritex extension officers about El Niño, so that they could help farmers make better decisions. However, it took several months for this to happen. Even though the workshops were late, Agritex did advise farmers prior to the normal planting time, soon after the release of the Meteorological Services Department seasonal forecast in early October 1997. Agritex instructed field staff to tell farmers that rainfall would be below normal. Agritex advised farmers to plant more drought-tolerant varieties of maize, or extremely drought tolerant crops like sorghum and millet, to plant early (October instead of November), and to sell off draft animals, where possible. The communal farmers received this information in conjunction with the media reports. Both the media and the Agritex field staff compared the current year with 1991–1992, when there was a massive drought in which even drought-tolerant crops had failed. Agritex deliberately tried to avoid conveying probabilistic forecasts down to the district and local level, out of fear of confusing the farmers. The workshops—planned in July 1997—took place in eight provinces between November 18 and December 5 1997 with representatives from the NEWU, Meteorological Services Department, and DMC. Provincial Agritex staff attended, and some district and local extension workers. This series of training sessions probably came too late to educate people for the 1997–1998 season, since they occurred after the time for early planting (October), and well after the time when communal farmers typically buy their seed (August and September). Furthermore, the vast majority of the local extension officers did not attend training sessions, and never learned about probabilistic forecasts associated with El Niño. Communal farmers reacted in many different ways to the deterministic forecasts. Some, particularly among those in wetter areas of the country did plant varieties of maize more drought tolerant than usual, and did plant early. Most communal land farmers did not change their behaviour in response to the forecast, and very few sold their animals. Some farmers, particularly among those in the driest regions, waited until December or January (i.e., late) to plant their millet, sorghum, or maize, after having seen early season rainfall turn out to be relatively normal. These farmers fared poorly when the rains ended early, as predicted. In total, the area of land the smallholder farmers planted was 21.3 percent lower than the year before, and the total harvest was 43.1 percent lower (Policy and Planning Division 1999). Those farmers who planted late suffered most.

(b) Media and Government

The media extensively covered the ENSO event and corresponding forecasts of drought, and for many people was the only source of climate-related information. People in the meteorology, food-security, and agricultural sectors were highly critical of the coverage that the media devoted to the ENSO event, accusing them of blowing it out of proportion. The feeling among professionals was that the media hype contributed to a poor understanding of the uncertainties associated with ENSO. Because they felt that the media overplayed El Niño, many saw their own role as trying to downplay the significance of the ENSO warm event, urging people not to panic. As the summer came to a close in March and April 1997, the Meteorological Services Department in Harare organized a post-season review meeting, where they reviewed with stakeholders the results of the forecasting effort during the season. The conclusion of the Meteorological Services Department was that the forecast of normal to below normal had been accurate. What was not accurate, they said, were the stories in the media predicting a major drought from “the mother of all El Niños,” reports that most people in the country read and used in making their decisions.

Early warning clearly worked during the 2002/03 crisis. It alerted local governments and the international community to looming food shortages as the harvest was just beginning, provided quantitative estimates of the number of affected households and the need for food aid and commercial imports, regularly updated these numbers through effective communications, and mobilized public opinion and resources to meet enough of those estimated needs to largely avert a humanitarian crisis. The early warning and response process also reflected an exceptional degree of collaboration among governments in the region, the emergency response community, and donor agencies. The way in which the work of national vulnerability assessment committee (VAC) was coordinated by the SADC Regional VAC and fed into donor and relief agency response is especially impressive. Darcy and Hofman (2003, p. 43) consider it a “striking example of a coordinated multi-agency assessment process” and suggest that the assessment methods, driven primarily by the Save the Children (UK) Household Economy Approach (HEA), achieved greater standardization than has been typical in past crises.

Monitoring drought presents some unique challenges because of its distinctive characteristics. Some of the most prominent challenges were as follows:

- Meteorological and hydrological data networks are often inadequate in terms of the density of stations for all major climate and water supply parameters. Data quality is also a problem because of missing data or an inadequate length of record;
- Data sharing is inadequate between government agencies and research institutions, and the high cost of data limits their application in drought monitoring, preparedness, mitigation and response;
- Information delivered through early warning systems is often too technical and detailed, limiting its use by decision makers;
- Forecasts are often unreliable on the seasonal timescale and lack specificity, reducing their usefulness for agriculture and other sectors;
- Drought indices are sometimes inadequate for detecting the early onset and end of drought;
- Drought monitoring systems should be integrated, coupling multiple climate, water and soil parameters and socio-economic indicators to fully characterize drought magnitude, spatial extent and potential impact;

- Impact assessment methodologies, a critical part of drought monitoring and early warning systems, are not standardized or widely available, hindering impact estimates and the creation of regionally appropriate mitigation and response programmes;
- Delivery systems for disseminating data to users in a timely manner are not well developed, limiting their usefulness for decision support.

Table 11 summarizes the 1991/92 drought response in Zimbabwe.

Table 11: Key events in Zimbabwe's drought response.

Date	Event
March 1991	3 million tonne grain shortfall for SADC region predicted for 1991/92 mkt. year - based on current grain stocks/harvest
April 1, 1991	GMB budgeted for maize to cover pre-harvest gap
July/August 1991	NEWU predicts zero closing stock of maize with GMB (by mkt. year end) due to poor harvest
October 1991	GMB officials went to RSA and arranged contract for 100,000 tonnes of maize
November 1991	NEWU drought forecast issued: warned of less than adequate stocks for Jan./Feb., and impending drought
December 1991	Tentative assessment of upcoming low grain harvest -- based on lack of rains
December/January	Rains failed (preventing maize tassel stage)
1st week of February, 1992	Appeals for emergency maize shipments
March 6, 1992	national drought disaster declared
March 1992	SADC REWS issues detailed forecast of upcoming harvest, having identified drought's magnitude -- regional import needs defined
June 1992	Official regional appeal made for donor assistance at Geneva pledging conference

Source: GMB, 1990, 1991, 1992; SADCC/REWS, 1991, 1992; SADC/FSTAU, 1993.

7 COMPARISON OF GLOBALLY AVAILABLE STATE-OF-THE-ART DROUGHT MONITORING SYSTEMS AND THOSE IN USE IN AFRICA

The framework diagram in **Figure 3** is used to guide the analysis. The framework conditions for user requirements are described in Chapter 6.

In this section drought monitoring systems identified in deliverable D2.1 are compared with the state of-the art drought monitoring systems in terms of purpose, tools, monitoring frequency, data captured, human capacity requirements, financing/cost. “State-of-the-art” is as described in this document and the fact sheets and detailed descriptions in **Appendix A and B**.

7.1 COMPARATIVE ANALYSIS OF FRAMEWORK CONDITIONS - OUTPUTS

This section highlights the main similarities and differences on outputs. The analysis considers how the identified outputs relate to the user requirements in Chapter 5 of this document.

7.1.1 North Africa – Algeria, Morocco and Tunisia (Maghreb Region)

Generally, In North Africa, there are no institutions, or departments within the institutions, dedicated only to drought studies, or even which have the drought studies as priority. However, several structures (Governmental institutions, agencies, ministries) intervene in this topic.

However, in Morocco, efforts to improve water use efficiency are investigated at a very high scale like investing in irrigation modernization or at smaller scale, in developing non-conventional water resources. This situation implies that drought adaptation is well implemented, but drought management is facing more reactive actions than proactive ones.

The most important institutions in part involved in drought, or being involved previously in drought studies, and the respective outputs which they can provide are summarized in **Table 12**. The Moroccan example is used here but the Algerian and Tunisian examples are similar.

Table 12: Institutions, outputs and data transfer

Outputs	DMN	DGH/ABH	CRTS	HCEFLCD	ONS	MAPM		
						ORMVA	DRA	Central Direction
Indices/ Statistics								
Average T°	X				X	X	X	X
Accumulated precipitations	X				X	X	X	X
Stream Flows		X			X			
Runoff		X						
Withdrawal potential		X			X			
Water balance		X			X			
Watertable		X			X			
Soil moisture				X	X	X		
SWSI					X			
RAN	X				X			
SPI	X			X	X			
PSDI	X				X			
NDVI			X		X			
SVI			X	X	X			
VCI			X	X	X			
TCI			X	X	X			
VH			X	X	X			
Bulletins	X		Monthly (October-May)+ SMAS(2006-2009)	SMAS(2006-2009)				X
Output indices frequency								
Daily		X						
Decadal		X						
Monthly		X	X					

Annual		X						
Punctually	X		X		X MEDROPLAN only			
Note: Data transfer: ⟶								

The indices used in Morocco are analyzed with reference to the 3 main inter-regional workshops held in **Nebraska-Lincoln** in 2009 (http://www.wmo.int/pages/prog/wcp/agm/meetings/wies09/index_en.html) , **Murcia** in 2010 (**http://www.usda.gov/oce/weather/private/murciaProceedings-FINAL_wCovers.pdf)** and **Geneva** in 2011 (http://www.wamis.org/agm/meetings/hdi11/S2-Stefanski.pdf) and which were designed to assess drought indices used around the word and to develop a consensus standard index for each of the meteorological, hydrological and agricultural drought. Lincoln declaration encouraged the national meteorological services to provide these information on their websites and to provide a manual for indices description.

7.1.1.1 Meteorological drought indices

Indeed, in Morocco, the only meteorological index which is produced is the SPI, by DMN, but only on an ad hoc, as for example during the SMAS project. Even if this institution may continue to produce occasional SPI, their use is internal and the results are not available to the public, they are not shared with other institutions either. Moreover, DMN which is the official institution of meteorological data collection, apply high prices for selling data which can limit their use and comprehension for other potential institutions. Moreover, no SPI index and/or description are available on the DMN website. The ONS also has produced the SPI during MEDROPLAN project.

7.1.1.2 Hydrological drought indices

The following indices taking into account streamflow, precipitation, reservoir levels, snowpack, groundwater levels have been selected:

- Surface Water Supply Index (**SWSI**)
- Aggregate Dryness Index (**ADI**)
- Normalised ADI (**NADI**) (Barua and Perera 2009)
- Streamflow drought Index (**SDI**) Nalbantis and Tsakiris (2009)
- Artificial Neural Networks (Perera et al. 2009)

While most of the necessary data for computing the cited indicators are collected by the Hydraulic Basin Agencies (ABHs), none of the recommended indices is produced by these institutions, and if there are so, no information is available to the public or to other institutions. In fact, hydrological droughts are described usually by the analysis of stream-flows, lake, or reservoir level data. This information is continually collected by the ABHs, but for water resources management and for hydrological models use.

Indeed, River basin agencies being the main water resources management institution at the regional level, their principal mission is to regulate water allocations within sectors (irrigation water, domestic, industrial), giving the priority to drinking water in case of low reservoir levels. The collected parameters, especially the average rainfall, the amount of water stored in dams and the situation of the main groundwater tables are themselves used as drought indicators, but no indices are produced, unless no ones are made available. However, SWSI index was produced by the ONS during MEDROPLAN project period, but the snow parameter was neglected.

7.1.1.3 Agricultural drought indices

No consensus was found for a unique agricultural drought index and 17 indices were selected, but all the recommended indices take into account soil moisture and crop growth. The NDVI was also designed as useful. Indeed, agricultural drought depends on the crop evapotranspiration demand and the soil moisture availability to meet this demand. Agricultural impacts of droughts are the result of short-term precipitation shortages, temperature anomalies that increase evapotranspiration demand, and soil water deficits. Hence, drought takes shorter to show up in agricultural than in hydrological sectors, especially in North Africa countries where 80 to 90% of agriculture relies directly to rain and does not receive water supply (except complementary irrigation in some cases). In Morocco, the ORMVAs, which are in charge of the irrigated areas, collect soil moisture and vegetation information, but not in a systematic way, and the deficit of precipitation is usually used as the main indicator/index of agricultural drought. This is the case also for the DRAs which are in charge of rain-fed agriculture.

Moreover, the NDVI is monthly produced by CRTS (The Royal Centre for Remote Sensing) which can be considered as having significant activities in terms of produced and published tools for drought monitoring. Through its bulletins, it describes evolving agricultural drought situations in different regions of Morocco on the basis of satellite imagery decadal analysis using NDVI . These bulletins are available on the CRTS website:

(http://www.crts.gov.ma/modules.php?name=Sections&op=viewarticle&artid=38).

CRTS also has produced many other indices, as shown on in **Table 12** during the SMAS project. However, the produced and published indices are too technical for the decision-makers and especially farmers, and need to be translated to a narrative way to assist decision-makers for the implementation of global strategic orientations.

7.1.1.4 Why the production of drought indices is limited?

With regard to drought indices lack in the North- African countries, 4 categories of limitations can be summarized. Case of Morocco

1. The inputs themselves are limited because not collected or because the range of structures is not available to replicate this process, which affects the quantity and/or the quality of the produced indices. For example, because snow parameters are not collected in a systematic manner, their integration in the calculation of SWSI index by the ONS during the MEDROPLAN (1998-1999) project was neglected. Another example concerns water consumption of crops, where we are used to consider equal to zero the drainage and runoff in the Penman equation for the evapotranspiration calculation, which may overestimate or underestimate the actual index value.

2. The outputs are not produced even when the necessary inputs are available. In this case, either it is estimated that the inputs themselves are reliable indicators and no need for indices outputs is expressed, as it is the case of the ABHs. Either the inputs are not available for other potential institutions which underline the lack of data sharing.

3. Some institutions may have the full capacity to produce valuable drought indices, but they do so only occasionally during specific projects or for scientific punctual studies. This is the case of the DMN where only few examples have been previously produced.

4. Other category of institutions, which like the CRTS produce continually significant indices for drought monitoring, but remains too technical for decisions-makers and especially for farmers, which lead to inadequate understanding. These institutions may have a considerable added value by developing guidelines.

7.1.2 Equatorial Lakes Region

7.1.2.1 Kenya

The prediction products are provided through outlooks for a decade, month and season. Consensus pre-season climate outlook which are also organised in conjunction with the major climate centres world-wide in order to derive a single consensus forecast for the region.

7.1.2.2 Rwanda and Burundi

Table 13 shows the parameters monitored and the frequency of monitoring in Rwanda and Burundi.

Table 13: Monitoring station network of Rwanda Meteorological Service

Type of station	Number	Parameter	Frequency
Agro-Synoptic	13	Temperature (Minimum and maximum air and soil temperature), Precipitation (in mm), Atmospheric Pressure, Wind speed and direction, Relative Humidity, Sunshine, Evaporation, cloud, visibility, ...	1&3 hourly and monthly
Climatological	25	Air temperature Precipitation (in mm)	10 days and monthly
Rainfall gauges	170	Precipitation in mm	Daily and monthly
Automatic weather stations	10	All parameters in digital format	Online measurement

Drought monitoring output is shared through media and printed bulletins. However, the dissemination of weather and climate information needs to be empowered at all level with involvement of various stakeholders and education/sensitization of the people to familiarize with use of weather information.

7.1.3 Eastern Nile Region (Downstream countries)

7.1.3.1 Comparative analysis - Egypt

Table 14 compares output data from monitoring systems in Egypt to “state of the art”

Table 14: Monitoring and Forecasting Systems in Regional and other systems relevant to Africa (Output)

System_ID	Output data	Similarities	Differences	System Level
DM-R01 To DM-R08	Indicators, Index. Data interpretation	The output is at Regional Level of applications	Different level of users	Regional system
DM-AC01 to DM-AC03	Meteorological Information	Network and experimental system	Purpose of the system	Africa Continental
DM-NNA01 to DM-NNA13	Meteorological Information with different frequency level. Maps, periodical repots	Application is at national level and regional level	Resolution level, tools applied	Northern Africa
DM-NEA01 to DM-NEA08	Meteorological Information with different frequency level.	The output at the national level and regional level	Resolution level, tools applied	Eastern Africa
DM-NSA01 to DM-NSA03	Meteorological Information with different frequency level	Most of the systems output serve early warning system		Southern Africa
DM-NWA01 to DM-NWA05	Meteorological Information with different frequency level	National and regional application	Frequency of output is varied	Western Africa
DM-ENA01 to DM-ENA04	Meteorological Information, land use and hydrolol gical data	Reginal application level (Medtirerraenan)	Output resolution & System Application	Europe and North Africa
DM-EAC01 to DM-EAC03	Early warning system		Output resolution & System Application	Europe and Continental Africa

7.1.3.2 Sudan

The purpose of global drought monitoring system is for quantitative monitoring for drought severity and its impacts on the population worldwide improve nations' capacity in risk preparedness and management, reduce social vulnerability to drought. While Sudan the monitoring systems are facing many challenges and problems in term of purpose, tools, monitoring frequency, data capture and human requirements which may be summarized as follow: Data availability and accuracy; data missing; data and information reliability; accessibility to data and information, and temporal and special coverage of meteorological stations; there is only 34 weather stations and around 300 rain gauges. There is lack of appropriate equipments and skilled staff for drought forecasting and monitoring:

- Poor spatial coverage and limit data acquisition, analysis and storage (in terms of number of stations, frequency of data capturing).
- Limited number of professional (this due to lack in-service trainings)
- Limited awareness to understand the contribution of drought monitoring in managing weather related risks as well as its contribution to the socio-economic development of the region.
- Networking, information exchange

7.1.4 Southern Africa

7.1.4.1 South Africa

Table 15 shows comparison of available monitoring output data generated in Globally, Europe and South Africa. The main similarities are that the countries produce meteorological data for use which in turn is used for monitoring drought risks and vulnerability. The countries in Europe, USA and Australia use remote sensing to get data and make it available to users who may need it whilst in South Africa it is not the case. South Africa produces only the SPI for the use in drought monitoring whilst there are a lot of other drought related indices that are produced globally and in Europe. The data released is mainly for the Southern region whilst coverage for European and global institutions is wider. The is less output of the river/stream flow data in South Africa as compared to other European countries. Hydrological droughts South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and farmers uses self-imposed restrictions among themselves to try and manage allocation. This is done by restricting themselves to 50% of their allocation and also physical inspection of rivers and stream along the farms for agricultural droughts

Table 15: Comparison of monitoring output data

ID	Institution	Output				Remarks
		Monitoring data	Forecasting data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
AFRICA						
ID: DM R 06	SARCOF	x	x			Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season
ID: DM N 08	SAWS	x	x	x		Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season, SPI
ID: DM R 07	FEWSNET	x	x			Rainfall, moisture index, land use , Elevation
	DWA	x			x	Department of Water in South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and taking into consideration upstream developments. In general drought warnings are issued after assessing the availability of water on the dams against the total allocations to users. The same approach for annual water allocation is applied with the lowest historical inflow and different allocations to irrigation farmers.
	FARMERS ASSOCIATIONS		x		x	• Impose self-restrictions among themselves to try and manage allocation. This is done by restricting themselves to 50% of their allocation. ○ If the dam overflows or is above 95% every month – receive 100% allocation • After end July every farmers gets 70% of his allocation • Have employed a water bay leaf – this person does physical inspection of rivers and stream along the farms. This is to check their levels so that a decision can be made on time in-terms

						of water availability • A technical committee has been put in place comprising of DWA,Letaba Water Users Association, South African Weather Services and Accu weather information.
GLOBAL						
ID: DM N 01	National Australia Bureau of Meteorology	X	X	X		Provides access to water and climate information: monitoring and forecast data, satellite data access to warnings and outlooks
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation		X		X	Collaborates with the Bureau of Meteorology
ID: DM N 03	Managing Climate Variability			X	X	An important outcome for drought management and forecasting is Climate Kelpie
ID: DM N 04	Australian Water Availability Project				X	Rainfall, solar radiation, maximum and minimum temperature from the Bureau of Meteorology
ID: DM N 05	Water Information Research and Development Alliance General information				X	Water balance reporting
ID: DM N 06	Climate Kelpie					A database which uses a small form at the top of the screen to search for records. The searcher can choose a region of interest, the commodity of interest and the topic of interest. Topics are: 'managing climate', 'see forecasts', 'understand climate' and 'ask a farmer'
ID: DM N 07	National Drought Mitigation Center	X				U.S. Drought Monitor Daily Gridded SPI Climate Division SPI US rain vs dry days VegDRI VegOut (vegetation Outlook) GRACE-based Water Storage

						Drought Impact Reporter
ID: DM N 08	National Weather Service	X	X	X		Temperature & Precipitation (6-10-day, 8-14-day. One month, 3 months) U.S. Hazards Outlook (3-7 day, 8-14 day, contours)
ID: DM N 09	National Climatic Data Center	X		X		Climate Division Standardized SPI Vegetation Health products via STAR – Center for Satellite Applications and Research
ID: DM N 10	High Plains Regional Climate Center	X				Summary maps of daily gridded SPI in collaboration with the NDMC.
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	X			X	Surface Water Supply Index – SWSI
ID: DM N 12	Bureau of Reclamation	X		X	X	Produces daily tabular data for other water systems and real-time reservoir teacup diagrams
ID: DM N 13	Bureau U.S. Army Corps of Engineers					Outputs and methods differ for different regional organisations
ID: DM N 14	National Aeronautics and Space Administration	X			X	Water storage assessments based on Satellite imagery like MODIS, GRACE etc.
ID: DM N 15	Geological Survey	X			X	WaterWatch & Drought watch - http://waterwatch.usgs.gov/ EROS Drought http://eros.usgs.gov/#/Science/Climate_Change/Drought VegDri - http://vegdri.cr.usgs.gov/viewer/viewer.htm
ID: DM N 16	University of Washington		X			Variable Infiltration Capacity (VIC)
ID: DM N 17	USFS Wildland Fire Assessment System	X	X			NDVI Greenness Keetch-Byram Drought Index Palmer Index
EUROPE						
ID: DM N 01	European Drought	X	X			Assessing, monitoring and forecasting droughts on a continental

	Observatory					level
ID: DM N 02	Drought Management Centre for South-Eastern Europe	X	X			-Air temperatures and surface water balance -SPI -Fraction of Vegetation Cover
ID: DM N 03	Hydrological drought evaluation system	X			X	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations, Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	X				Daily Gridded SPI Climate Division SPI
ID: DM N 05	System of Prediction and Management of Droughts	X				Enables managers and users of water resources with an instrument that allows the anticipation of the potential impacts of drought situations, in order to promote the implementation of mitigation measures.
ID: DM N 06	The Drought Bulletin	X				The regional drought bulletins are provided by different entities based on monthly SPI
ID: DM N 07	Drought evaluation - Environment Agency	X			X	Ensures that water companies have effective plans in place to maintain public water supplies during a drought without damaging the environment
ID: DM N 08	Integrated project on water and global change				X	Brings together hydrological, water resources and climate communities
ID: DM N 09	XEROCHORE	X	X	X	X	Exploration of hydro climatic aspects of drought, propagation of meteorological droughts into hydrological droughts, integrated drought assessment framework (hydrology and climate), drought monitoring (incl. early warning) and forecasting
ID: DM N 10	Drought preparedness network for the Mediterranean	X				- Drought management Guidelines. Paper, website and CD versions -Tutorial of the Drought Management Guidelines. Website and CD -Technical Annexes of the Drought Management Guidelines

7.1.4.2 Zimbabwe

The institutions used in the analysis are: Meteorological Services Department, SADC Drought Monitoring Center, SARCOF and ZINWA. The main similarities are that the output data is mainly for the purposes of drought forecasting; warning and response. The output data type is mainly climatic data. Output data for state for the art includes drought monitors, impact reporter and SPI for National and sub national levels, whereas for Zimbabwe more emphasis is on assessments. STAR –Global Vegetation Health products: VCI, TCI, VHI, SSI, SMN, SMT, FRI, Drought, Malaria, VH, Ecosystems, are some of the outputs from state of the art environment which are not common for Zimbabwean conditions. Outputs for sate of the art are broad and diverse and as such capture virtually all user needs. The comparison with 'state of the art" is shown in **Table 16**.

Table 16: Comparison of monitoring output data

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	**Africa :Zimbabwe**	
SADC Drought Monitoring Center and Drought Management Centre for South-Eastern Europe (DMCSEE)	**Coverage**			Both are Regional and cover large areas, which combined several countries.SADC DMC , covers southern Africa and DMCSEE covers South –eastern Europe
	Frequency	Maps are updated twice per month. Final data maps with two months delay are available after 20th day of the current month. First-guess maps are available after 5th day of the next month.	Generate medium-range (10-14 days) and long-range climate outlook products on monthly and seasonal (3-6 months) timescales.	Frequency is almost similar
	Purpose		monitor floods	Monitoring and assessment of drought risks and vulnerability
	Output data			Both provide Drought Monitoring bulletins and maps
Meteorological Services Department (Zimbabwe) and Australia Bureau of Meteorology	**Coverage**			Both provide national coverage
	Frequency	For most parameters the time periods are: Day, week, month, 3months,	Day;5 day; monthly and seasonal forecasts	

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	Africa :Zimbabwe	
		6months, 12monhths		
	Purpose			Monitoring, Forecasting, warning, response
	Output data	- weekly rainfall update - Seasonal rainfall outlooks - Seasonal Temperature outlooks - Seasonal Streamflow Forecasts - Climate statements archive	Rainfall; temperature; atmospheric pressure; wind forecast data. satellite images and outlook maps.	Little or less provision of stream flow, runoff and hydrological data.
ZINWA and Water Information Research and Development Alliance	**Coverage**	National Level (Australia)	National (Zimbabwe)	
	Frequency		Weekly and seasonal	
	Purpose		planning, coordination, management of water resources and the delivery of water	Monitoring, forecasting
	Output data	Precipitation and actual evaporation products, seasonal and short- and long-term water forecasting and	Stream levels; runoff data. Evaporation data;	

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	**Africa :Zimbabwe**	
		prediction, Water information Models and water data transfer standards		
AGRITEX in collaboration with NEWU and FAO and Managing Climate Variability/ Climate Kelpie	**Coverage**			National
	Frequency		Monthly; Seasonal	
	Purpose		Assessment of vulnerability status	warning, response
	Output data	a database providing access to weather and climate forecasts and projections at other institutes, mostly the Bureau of Meteorology	Crop assessment reports. Food security status	

7.1.5 West Africa - Mali

Table 17 compares output data from monitoring systems in Mali to "state of the art"

Table 17: Comparison of monitoring output data

ID	Institution	Output				Remarks
		Monitoring data	forecasting data	satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
			AFRICA			
	Meteo Mali and Meteo France	x	x			Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season
	AGRHYMET/ PRESAO Nationale Directorate of Hydrology					Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season, SPI
	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	x			x	Rainfall, moisture index, land use , Elevation
	The information comes from AGRHYMET and the National Directorate of Hydrology.		x			Department of Water in South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and taking into consideration upstream developments. In general drought warnings are issued after assessing the availability of water on the dams against the total allocations to users. The same approach for annual water allocation is applied with the lowest historical inflow and different allocations to irrigation farmers.
			GLOBAL			
ID: DM N 01	National Australia Bureau of Meteorology	x	x	x		Provides access to water and climate information: monitoring and forecast data, satellite data

						access to warnings and outlooks
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation		x			Collaborates with the Bureau of Meteorology
ID: DM N 03	Managing Climate Variability			x		An important outcome for drought management and forecasting is Climate Kelpie
ID: DM N 04	Australian Water Availability Project				x	(rainfall, solar radiation, maximum and minimum temperature) from the Bureau of Meteorology
ID: DM N 05	Water Information Research and Development Alliance General information					Water balance reporting
ID: DM N 06	Climate Kelpie					A database which uses a small form at the top of the screen to search for records. The searcher can choose a region of interest, the commodity of interest and the topic of interest. Topics are: 'managing climate', 'see forecasts', 'understand climate' and 'ask a farmer'
ID: DM N 07	National Drought Mitigation Center	x				U.S. Drought Monitor Daily Gridded SPI Climate Division SPI US rain vs dry days VegDRI VegOut (vegetation Outlook) GRACE-based Water Storage Drought Impact Reporter
ID: DM N 08	National Weather Service	x	x	x		Temperature & Precipitation (6-10-day, 8-14-day. One month, 3 months) U.S. Hazards Outlook (3-7 day, 8-14 day, contours)
ID: DM N 09	National Climatic Data Center	x		x		Climate Division Standardized SPI Vegetation Health products via STAR – Center for Satellite Applications and Research
ID: DM N 10	High Plains Regional Climate Center	x				Summary maps of daily gridded SPI in collaboration with the NDMC.
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	x				Surface Water Supply Index – SWSI
ID: DM N 12	Bureau of Reclamation	x		x		Produces daily tabular data for other water systems and real-time reservoir teacup diagrams

ID: DM N 13	Bureau U.S. Army Corps of Engineers				x	Outputs and methods differ for different regional organisations
ID: DM N 14	National Aeronautics and Space Administration	x				Water storage assessments based on Satellite imagery like MODIS, GRACE etc.
ID: DM N 15	Geological Survey	x			x	WaterWatch & Drought watch - http://waterwatch.usgs.gov/ EROS Drought http://eros.usgs.gov/#/Science/Climate_Change/Drought VegDri - http://vegdri.cr.usgs.gov/viewer/viewer.htm
ID: DM N 16	University of Washington		x			Variable Infiltration Capacity (VIC)
ID: DM N 17	USFS Wildland Fire Assessment System	x	x			NDVI Greenness Keetch-Byram Drought Index Palmer Index
			EUROPE			
ID: DM N 01	European Drought Observatory	x	x			Assessing, monitoring and forecasting droughts on a continental level
ID: DM N 02	Drought Management Centre for South-Eastern Europe	x	x			-Air temperatures and surface water balance -SPI -Fraction of Vegetation Cover
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations, Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x				Daily Gridded SPI Climate Division SPI
ID: DM N 05	System of Prediction and Management of Droughts	x			x	Enables managers and users of water resources with an instrument that allows the anticipation of the potential impacts of drought situations, in order to promote the implementation of mitigation measures.
ID: DM N 06	The Drought Bulletin	x				The regional drought bulletins are provided by different entities based on monthly SPI
ID: DM N 07	Drought evaluation - Environment Agency	x				Ensures that water companies have effective plans in place to maintain public water supplies during a drought without damaging the environment
ID: DM N 08	Integrated project on water and global change				x	Brings together hydrological, water resources and climate communities
ID: DM N 09	XEROCHORE	x	x	x	x	Exploration of hydro climatic aspects of drought,

						propagation of meteorological droughts into hydrological droughts, integrated drought assessment framework (hydrology and climate), drought monitoring (incl. early warning) and forecasting
ID: DM N 10	Drought preparedness network for the Mediterranean	x				- Drought management Guidelines. Paper, website and CD versions -Tutorial of the Drought Management Guidelines. Website and CD -Technical Annexes of the Drought Management Guidelines

7.2 COMPARATIVE ANALYSIS OF FRAMEWORK CONDITIONS – INPUTS

The comparative analysis of the framework conditions related to the inputs to drought monitoring in North-Africa will be done though the answer to different questions related to:

- type of institutions involved in drought monitoring
- the characterisation of monitoring networks and types of data they collect
- how is data managed

7.2.1 Institutions in charge of drought monitoring

The review of the state of the art drought monitoring systems (US, Australian and European Drought monitoring systems) revealed, as shown in Figure 1, a hierarchy in the responsibilities of each institution involved in drought monitoring with 4 different levels of implication. It also shows the creation and implementation of institutions and systems solely and specifically involved in drought monitoring. This is for example the case of the US National Drought Mitigation Centre or of the European Drought Observatory which one can describe as systems since they benefit from the contribution of several different institutions.

7.2.2 North Africa – Algeria, Morocco and Tunisia (Maghreb Region)

In north-Africa, these types of hierarchy and "specialisation" are not that clear. As a matter of fact, drought monitoring is conducted by institutions or ministerial departments that we would mainly classify as level 1 institution, namely institutions that operate in situ monitoring networks or satellite observations. In addition, they (at national or sub-national levels) are generally not specifically oriented and "devoted" towards drought monitoring which often represents only and indirect objective of their activities and not a dedicated purpose. Indeed, in Morocco or in Algeria, the river basin agencies and the ANRH (see D 2.1 fact sheets n° 2, 3 and 8) monitor water resources, agricultural departments monitor agricultural and socio-economic drought impacts but none of them has a specific department dedicated to drought. Thus, if we go further into this comparison, the most important difference is the lack of level 3 institutions, i.e. drought oriented institutions that process data and provide information to the public or institutions that collect data and maintain data bases. At the north-African level, the only example of institution that could be classified as a level 3 institution is the Moroccan National Drought Observatory which was implemented in 1981 with the support of the US National Drought Mitigation Center. At the time of its creation, the specific objective of the NDO in terms of drought monitoring were to collect and gather drought related data from other Moroccan institutions in charge of meteorological, hydrological and agricultural monitoring networks in order to process and analyse them and provide drought related information in a timely systemic manner. Thus, the observatory was implemented as a system designed to operate as an institutional network. Unfortunately, due to a lack of funding, communication, and data flux between the different monitoring networks, the NDO is not fully operational at present. Another reason may be the lack of legal framework. Indeed, if we refer to the Australian drought monitoring system, hundreds of different institutions are now required by law to provide their water information the Bureau of Meteorology (BOM) which was the case of the National Drought Observatory.

7.2.2.1 Drought monitoring networks and types of data

In North-Africa, drought is monitored like globally through in-situ networks or satellite images. **Table 18** presents the different types of raw data collected by the Moroccan institutions. The analysis of Algerian and Tunisian drought monitoring activities achieved in D2.1 reveal the same types of collected data. These raw data or satellite images are used as inputs to produce drought indices. However, some of them are often directly used to monitor drought. These are mainly agricultural or forest data such as the evolution of forest and rangelands areas, the ploughed fields and cereal seedling situations, the use of entrants (fertilizers, pesticides..) or socio-economic data which are in fact drought impact indicators.

Table 18: Types of data collected by institutions involved in Drought monitoring Morocco

Type of data collected	Name of the Institution					
	National Directorate of Meteorology	River basin agencies and General Directorate of Hydraulics	Royal Centre of Remote-sensing	High Commissariat for water, forests and fight against Desertification	National Drought Observatory	Ministry of Agriculture and maritime Fisheries
Precipitation	X	X		X	X	X
Temperature	X	X		X	X	X
Atmospheric pressure	X			X		X
Wind direction and speed	X			X		X
evaporation	X	X		X		X
Snow cover	X					
Stream flows		X			X	
Reservoir levels		X			X	
Floods		X				
Groundwater		X			X	
Water supply		X				
Fire				X		
Soil texture				X		X
Soil Depth				X		X
Soil Moisture				X		X
Satellite images			X			
Evolution of forest and rangelands areas				X		
Field surveys, length of						X

the agricultural season						
Food and water availability for livestock						X
Socio-economic data (Commodity prices, feed prices, data on agricultural seasonal jobs, rural migration...)						X

If we compare the inputs to the “state of the art” drought monitoring networks to the north-African ones, the main shortcomings in terms of types of collected data seem related to soil moisture and snow pack.

Indeed, soil moisture is an important variable for the characterisation of agricultural drought and agricultural drought monitoring at the Australian, European or north-American levels rely on in-situ measurements or soil moisture estimations based on radar satellite images. For example, the institute of photogrammetry and remote-sensing of the Vienna University of Technology (Austria) develop global, coarse-resolution soil moisture data (25-50 km) derived from backscatter measurements acquired with scatterometers onboard the satellites ERS-1 and ERS-2 (1991 to present) and the three MetOp satellites (2006-2020).

In Morocco, soil moisture measures by gravimetric are achieved by some institutions like the HCEFLCD and the ORMVAs but not a systemic and generalised way and consequently data are not available on long range time or space series. At the north-African level, several studies report the use of satellite images from soil moisture estimation. Thus, Zribi *et al*. (2011) presented an approach for the estimation and monitoring of soil moisture in Tunisia using ENVISAT ASAR images, over two types of vegetation covers. In a study conducted in the Merguellil basin, situated in central Tunisia, Lili Chaabane *et al*. (2010) used two soil moisture products derived from ERS Scatterometer data over the period 1991-2006. These are however punctual studies and the use of satellite images for soil moisture monitoring and agricultural drought monitoring is still not performed at large scale in North-African drought monitoring systems.

Snow pack monitoring is an important feature of the “state of the art” drought monitoring systems especially in areas where snow represents an important component of the hydrological cycle. It is one of the inputs to the computation of one of the most commonly used hydrological drought index: the surface water supply index (SWSI). Despite the low latitude, Moroccan mountains have frequent and important snowfalls in November and

December and more in January and February. Snow in the High Atlas Mountains forms the main source of freshwater for the arid lowlands of south-eastern Morocco. All large rivers and reservoir refill levels depend on maximal seasonal runoff generated by snow and rainfall events during the winter. Agriculture in the mountain valleys and the foreland basins depends on irrigation by canals diverted from snowfed rivers. Drinking water in mountainous areas is limited to springs connected to the villages by plastic pipes (Shultz and De Jong, 2004).

Despite this real importance of snow in the regional water balance and as an indicator of climate change, its monitoring is still not fully integrated into the drought monitoring activities. However, in a context of increasing water scarcity, snow research is becoming of increasing interest to water management institutions. Thus, several studies are now focusing on the characterization of snow cover thanks to in situ measures and by remote-sensing. Currently, the network of hydro-climate measures in the mountains is often very sparse although it knew some improvement during the past decade: In 2001, the GLOWA-impetus project implemented 5 automatic weather stations in the M'Goun (High Atlas Mountain range) region at altitudes between 1900 and 3850 m. The 3 highest stations were equipped with ultra-sonic snow depth sensors, infrared temperature sensors for surface temperature measurements and temperature probes for snowpack temperature measurements. In 2009, The National Meteorological Service of Morocco (DMN) improved its own network measuring snow depth thanks to 03 ultrasonic sensors. The GLOWA-IMPETUS project used MODIS (500m resolution) time series at daily and weekly intervals to monitor snow dynamics using the Normalized Difference Snow Index (NDSI).

Boudhar et al., (2007) used a 7-year time series of SPOT-VEGETATION images to map snow covered areas in the High Atlas mountains. This study demonstrated that remote sensing data can be used for long-term observation of the inter- and intra-annual variability of snow covered areas in a region where the meteorological observation network is insufficient.

7.2.2.2 How drought monitoring data is collected

(a) Satellite based drought monitoring

In North-Africa, satellite-based drought monitoring is conducted by national Centers of Remote sensing (CRTS (Morocco), CNCT (Tunisia) D 2.1 fact sheet n°4 and 11) which activities towards drought monitoring focus mainly on vegetation monitoring thanks to low resolution images (NOAA/AVHRR). In Morocco, forest fires constitute a permanent problem, in particular during summer seasons and drought periods. Thus, the CRTS developed a forest fire monitoring methodology based on earth observation data in low spatial resolution. The inputs to this tool are satellite images for the identification of forest fire risk areas, the detection and characterization of hot spots and the cartography of burned areas. Similar activities are conducted in Tunisia.

In the United-States, the satellite based drought monitoring includes vegetation monitoring but integrate also the monitoring of the hydrological cycle thanks to produce like MODIS and Grace. In Morocco, satellite imagery and the METRIC surface energy balance method were used to derive reasonable and objective estimates of crop evapo-transpiration (ET) in three irrigation sectors. This metric analysis required satellite imagery with thermal (surface temperature) information as well as high quality weather data. Both Landsat and MODIS satellite images were used in this study (Polly and Martin, 2011).However, the satellite based monitoring of the hydrological cycle is still a component of specific studies and not an official component of the drought monitoring systems in North-Africa and it seems that the costs and availability of those images still represents a barrier to the development of their use. However, the Arab land data assimilation system, which is a US Aid funded project involving the NASA, the Arab council for water, the World bank and other institutions is now aiming to fill this gap. As a matter of fact, the main goal of this project is to produce maps with a 1/8th grid coverage of hydrological states and fluxes in the Middle-East North-Africa (MENA) region thanks to Modis and Grace observations. This will allow:

- A near real time monitoring of water resources
- A rapid assessment of the severity and extent of droughts and floods

(b) In-Situ drought monitoring

In North-Africa, drought monitoring is mainly achieved through networks of in-situ monitoring points and consists of the gathering of hydrological, meteorological, agricultural and socio-economic data.

As in the case of Europe, Australia or in the US, land surface observations networks use the following tools:

- Precipitation: Surface gages and Doppler radars
- Other meteorological parameters: Synoptic weather stations
- Soil parameters: field experiments
- Vegetation parameters: field experiments
- Ground water: well observations
- Stream flows: stream gauges

However, the first question here is related to the density of monitoring points. In Morocco, the National Directorate of meteorology (DMN) had in 2010 a network of 42 synoptic meteorological stations (**Figure 4**) in addition to hundreds of precipitation gages stations. But according to Nouni (2010), the Moroccan observation network is currently not very dense and is partially automated. The weather observation in Morocco depends largely on the human presence. That implies necessarily the absence of meteorological data on large regions of Morocco and in case they are present their concentration and their treatment remains difficult. In addition, the Moroccan automatic weather station network presents several problems:

- Low density of the network and bad distribution
- Variety of data storage format
- Lack of automatic transmission solution of the observed data
- Not automatic coding meteorological message of observed data in accordance with WMO
- Data transmission require in most cases human intervention and the passage through other local treatment system
- Data transmission is done by technical means becoming obsolete and expensive: the analogue leased lines

The VIGIOBS project (see **Figure 5**) came to address these issues for a better distribution of the Moroccan observation network and aims at implementing during the period 2010-2012:

- 3 Doppler Weather Radar to cover East Region, South-East and South regions
- 60 synoptic automatic weather stations;
- 90 auxiliary automatic weather stations;
- 06 automatic weather stations in mountain areas;
- 03 Upper air stations

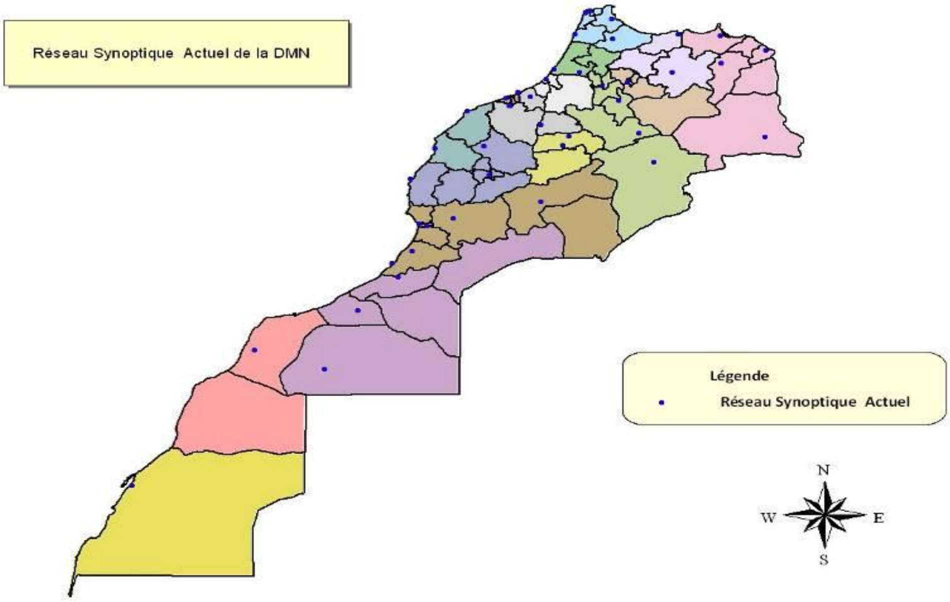

Figure 4: Synoptic station network of the DMN in 2010.

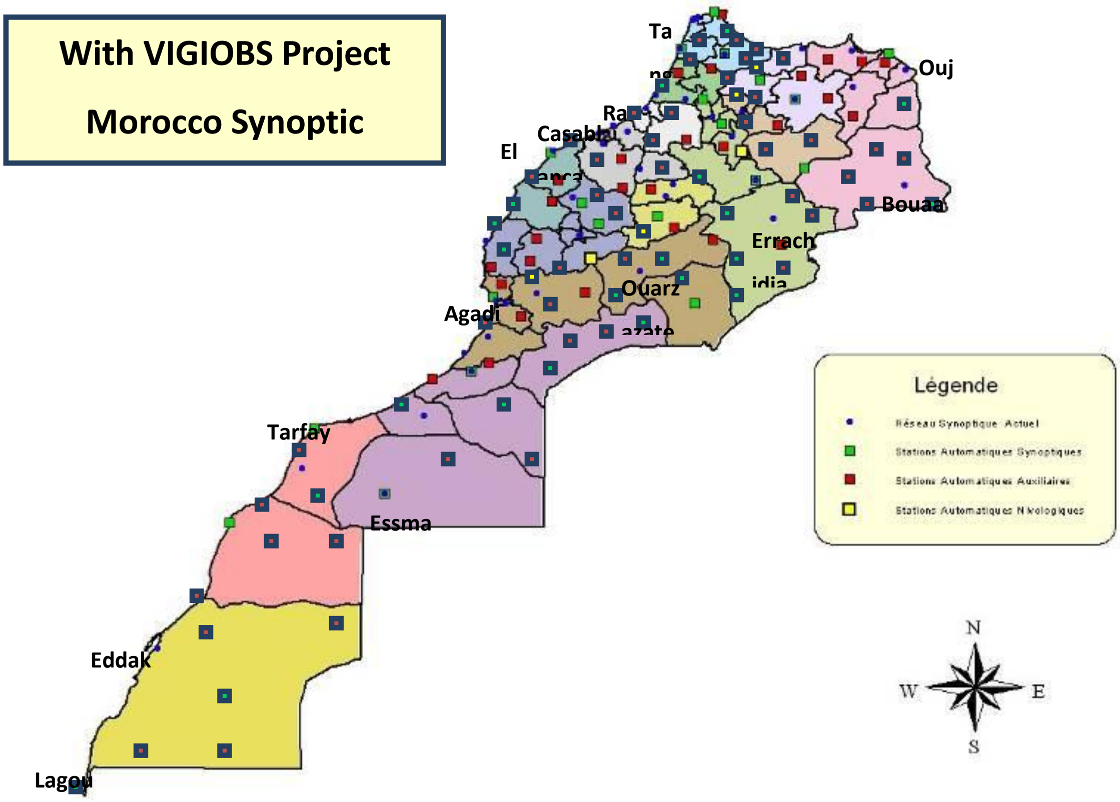

Figure 5: VIGIOBS project: Synoptic station network of the DMN by 2012

The river basin agencies, the Regional directions of Agriculture and the ORMVAs also have their own rainfall gages and meteorological stations networks which are still under construction. Thus, if we refer to the Oum er-Rbia basin, the regional direction of Agriculture, in charge of rainfed areas, started in 2000 a modernisation of the rainfall gages in the area under its management and implemented 3 fully automated meteorological stations. Other rainfall measures are still done empirically thanks to graduated burettes. The ORMVA of Tadla, in charge of the irrigated perimeters of Beni-Moussa and Beni-Amir has three automated weather stations. The Ouled Gnaou station (450 m hight, Latitude = 32,3° and Longitude=6.3°) is the automatic meteorological station situated in the Beni-Moussa perimeter within a big experimental station. It is representative of climatologic features of Tadla perimeter. Data from this station cover all meteorological parameters such as temperature, wind speed, relative humidity. In addition to the DMN, DRA and ORMVAT, the river basin agency of Oum er-RBia has its own network of rainfall gages with a higher density of monitoring points in the high Oum er-Rbia sub-basin (mountain areas) compared to the low Oum er-Rbia sub-basin (plain and coastal areas). These different institutions provide a full and good coverage of the basin in terms of density of rainfall gages but the number of fully automated and complete meteorological stations is weak and still needs to be increased especially if we take into account the lack of cooperation and data flux between the different institutions in charge of rainfall monitoring. According to Jalil (2010), the objective for the Sebou basin (Morocco) is to implement a climatologic network of reference according to the standards of minimum density of rainfall stations of the WMO (Table XXX)

Table 19 presents the minimum density of rainfall stations according to WMO standards and geographic units.

Table 19: Minimum density of rainfall stations according to WMO standards

Geographic Unit	Minimum density (area in km^2 by rainfall station)
Coastal areas	900 (30 km x 30 km)
Mountain areas	250 (16 km x 16 km)
Interior plains	575 (24 km x 24 km)
Hills	575 (24 km x 24 km)

In Morocco, the river basin agencies are in charge of surface and ground water monitoring. According to the values presented in **Table 20** which gives the minimum density of hydrometric stations recommended by the WMO, river basin agencies in Morocco present a fairly good coverage of their area of action.

Table 20: Minimum density of hydrometric recommended by the WMO

Geographic Unit	Minimum density (area in km^2 by hydrological station)
Coastal areas	2750
Mountain areas	1000
Interior plains and Hills	1875

As a conclusion, the main shortcomings regarding rainfall and flow measurements networks seem more related to the following points than the density of monitoring points:

- The maintenance and the obsolence of the monitoring networks
- The reliability of data and data quality analysis
- The percentage of missing data and the availability of long term series of data
- The frequency of measures and the continuity of data monitoring

7.2.2.3 Data management

The review of the state of the art drought monitoring systems showed that one of their main common “added value” is data management. Thus, there is often an automated flow of the data from observation networks to databases managed by specialised institutions that conduct first quality cheks analysis on the data and then make the row data or process data available in these public or private databases. That is for example the case of the US Applied Climate Information System (ACIS) *(http://www.rcc-acis.org/)*. ACIS was developed and is maintained by the NOAA Regional Climate Centers (RCCs) to manage the flow of information from climate data collectors to the end users of climate information. The situation is clearly different in North-Africa where there is an important gap in data management. Thus, the availability of data from monitoring networks (with free access or with access from official partnerships agreements) still needs to be improved. In addition, even if data and/or databases are proprietary, knowing they are there is still useful, which is not actually the case from many north-african drought monitoring institutions. Consequently, there is an important need in improving or coordinating the flow of data and this may be achieved by:

- Maximising communication and transparency
- Maximising cooperation and coordination between institutions
- Providing equal and better access to information
- Feeding information to users rather than users having to find information
- Implementing available databases

This last point is of great importance. In Morocco, in a good attempt to achieve a better management of hydrological data at the national level, a database for water resource management called Water resources database for the 21st century (BADRE21) was implemented. This database has been constructed since 1995. The system was developed by the State Secretary for Water and Environment (SEEE) to be a centralized system where all data is entered in the centre at SEEE office in Rabat. The system operation was then decentralized and the system software was replicated in the 7 basin agencies (HBA). Structured in five parts (data base settings, site reports, reports on measurements, data transfer and editing), it is fed textual and raw numerical data. DRH feeds information to ABH and the worked-out data can take the opposite direction. The five parts that make up this system concern dams, hydrometric stations, boreholes/wells/streams, water quality, and rainfall/climatology

Regarding climatologic data management, the DMN (Morocco) also improved its database managements systems. Thus, before 2000, documents (CRQ, TCM..) were sent to the central administration of the DMN, archived and stored there in the CLICOM database. Starting from 2000, documents (CRQ, TCM..) are sent from stations to the Regional Directions of Meteorology (DRMs) and stored in ORACLE database (GDCLIM). The data entered at the 4 DRMs are then integrated to the central database (Joubij, 2010).

7.2.3 Equatorial Lakes Region

7.2.3.1 Kenya

Satellite technology is coming to the aid of pastoralists in drought-stricken Kenya, with the expansion of a water monitoring system that aims to reduce livestock loss.

The Livestock Early Warning System combines information uploaded by villagers with satellite data to create a virtually real-time map of forage and water conditions.

A successful pilot project in Turkana district in northwest Kenya is being considered for extension across the country.

"The whole idea is to automate the process of providing information on water conditions in the pastoral areas in a reliable, timely and consistent manner," said Laban MacOpiyo, the scientist in charge of the project at the University of Nairobi.

The system uses technology developed by Texas A&M University in the United States and has been used in several states there, as well as in Mali and Mongolia.

7.2.3.2 Rwanda and Burundi

There is a great similarity on main weather and climate information collected in Rwanda and in Burundi compared to other countries. The common parameters (input data) are temperature, wind, precipitation, evaporation, sunshine, pressure, cloud, visibility, etc. However, some additional information is not collected locally due to the lack of appropriate equipment like upper air station, RADAR, etc. Compared to the state-of-the-art drought monitoring systems, in Rwanda and Burundi, data are mostly observed manually (with few automatic stations), while in developed countries weather and climate information is monitored automatically and online.

7.2.4 Eastern Nile Region (Downstream countries)

7.2.4.1 Comparative analysis - Egypt

Table 21 compares input data from monitoring and early warning systems in Egypt to "state of the art"

Table 21: Monitoring and Forecasting Systems in Regional and other systems relevant to Africa (Inputs)

System_ID	Input data	similarities	Differences	System Level
DM-R01 To DM-R08	Precipitation, land use data , meteorological data, EO data, Hydrological data	Regional Level of applications,	Different regions application, beneficiaries from the system	*Regional system*
DM-AC01 to DM-AC03	EO data Measured data (based on the case study)	Water Resources Management Networking and experimental systems	System application distribution over different African countries,	*Africa Continental*
DM-NNA01 to DM-NNA13	Meteorological data, Hydrological data, land use	Water resources management System Beneficiaries	Tools applied and system analysis and Data frequency	*Northern Africa*
DM-NEA0 to DM-NEA08	Meteorological data observation	Water resources management System Beneficiaries	System beneficiaries and technology used, Data frequency	*Eastern Africa*
DM-NSA01 to DM-NSA03	Observation darta and EO data		System beneficiaries,	*Southern Africa*
DM-NWA01 to DM-NWA05	Meteorological data observation			*Western Africa*
DM-ENA01 to DM-ENA04	Meteorological data observation, land use, soil information	Regional application level (Meditrearran), water resources in		*Europe and North Africa*
DM-EAC01 to DM-EAC03	Eo data, Metrological data	Regional application level		*Europe and Continental Africa*

7.2.4.2 Sudan

Data collection and frequency

- The SMA collects weather parameters
  - Rainfall, Maximum and minimum Temperature, Wind speed and direction, Relative humidity, Sunshine and sun radiation, Evaporation; from ground stations (Traditional and automatic).
- Sea Surface Temperature (SST)
- Clod Cloud Duration (CCD).
- Normalized Difference Vegetation Index (NDVI).

Spatial Resolution: for the monitoring of the weather data there is around 34 stations (in capital cities in the country) and around 3000 rain gauges.
Frequency of input: hourly, daily, monthly and annual basis

7.2.5 Southern Africa

7.2.5.1 South Africa

Table 22 compares input data generated in Global, European early warning systems with those in South Africa. The meteorological data is mainly used as an input data to the models Globally, in Europe and also in Africa. Hydrological data is mainly used in European countries as historical data is readily available. South Africa still has a challenge of capturing hydrological data as there are few records available. There is a decline on the meteorological stations in South Africa due to high maintenance costs.

Table 22: Comparison of monitoring input data

ID	Institution	Input				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
AFRICA						
ID: DM R 06	SARCOF	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 08	SAWS	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM R 07	FEWSNET	x				Rainfall, moisture index, land use , Elevation
	Department of Water Affairs	x			x	Department of Water in South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and taking into consideration upstream developments. In general drought warnings are issued after assessing the availability of water on the dams against the total allocations to users. The same approach for annual water allocation is applied with the lowest historical inflow and different allocations to irrigation farmers.
	FARMERS ASSOCIATIONS		x		x	• Impose self-restrictions among themselves to try and manage allocation. This is done by restricting themselves to 50% of their allocation. • If the dam overflows or is above 95% every month – receive 100% allocation • After end July every farmers gets 70% of his allocation • Have employed a water bay leaf – this person does physical inspection of rivers and stream along the farms. This is to check their levels so that a decision can be made on time in-terms of water availability

ID	Institution	Input				Remarks
						A technical committee has been put in place comprising of DWA, Letaba Water Users Association, South African Weather Services and Accu weather information.
				GLOBAL		
ID: DM N 01	National Australia Bureau of Meteorology	x				Climate variability (wind speed, direction, temperature and insulation)
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation	x		x		Different satellites provide this information.
ID: DM N 03	Managing Climate Variability	x				To improve communication between scientists and farmers. Same as Kelpie
ID: DM N 04	Australian Water Availability Project	x			x	Daily fields for rainfall, maximum and minimum temperature, continental observations of brightness temperature (BT) several times daily.
ID: DM N 05	Water Information Research and Development Alliance General information	x	x			knowledge and experience of the collaborating partners
ID: DM N 06	Climate Kelpie					
ID: DM N 07	National Drought Mitigation Center	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 08	National Weather Service	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 09	National Climatic Data Center	x	x			In-situ data, satellite and model data, paleoclimate data and data from NOAA's Regional Climate Centers.
ID: DM N 10	High Plains Regional Climate Center	x	x			Stations used are from the National Weather Service Cooperative Observer Network (COOP), and the Automated Weather Data Network (AWDN).
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	x	x			NRCS collects data via in-situ networks National Weather Service

ID	Institution	Input				Remarks
ID: DM N 12	Bureau of Reclamation	x				Generates data based on in-situ measurements.
ID: DM N 13	Bureau U.S. Army Corps of Engineers	x	x	x	x	In-situ measurements form the input for drought monitoring and alarms
ID: DM N 14	National Aeronautics and Space Administration	x		x		Different satellites provide this information.
ID: DM N 15	Geological Survey			x	x	Hourly in-situ measurements of over 3,000 stream gauges
ID: DM N 16	University of Washington	x	x			Inputs are time series of daily or sub-daily meteorological drivers (e.g. precipitation, air temperature, wind speed) Land-atmosphere fluxes, and the water and energy balances at the land surface, are simulated at a daily or sub-daily time step
ID: DM N 17	USFS Wildland Fire Assessment System	x		x		NOAA's AVHRR satellite products for NDVI; and weather station precipitation, latitude, dry bulb temperature for the Keetch-Byram Drought Index
			EUROPE			
ID: DM N 01	European Drought Observatory	x	x	x		Daily moisture data and daily soil moisture anomaly
ID: DM N 02	Drought Management Centre for South-Eastern Europe			x		
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x		x		NOAA's AVHRR satellite products for NDVI; and weather station precipitation, latitude, dry bulb temperature for the Keetch-Byram Drought Index
ID: DM N 05	System of Prediction and Management of Droughts	x			x	Meteorological conditions (namely reduced precipitation leading to drought situations); Available storage capacities (availability in the main water sources);

ID	Institution	Input				Remarks
						Consumption requirements for the main water users; Socioeconomic effects associated to drought due to water availability limitations.
ID: DM N 06	The Drought Bulletin	x	x			Monthly cumulated precipitation values
ID: DM N 07	Drought evaluation - Environment Agency	x		x		In-situ data, satellite and model data, paleoclimate data and data from NOAA's Regional Climate Centers.
ID: DM N 08	Integrated project on water and global change	x			x	precipitation and temperature
ID: DM N 09	XEROCHORE	x	x	x	x	Meteorological conditions (namely reduced precipitation leading to drought situations); Available storage capacities (availability in the main water sources); Consumption requirements for the main water users; Socioeconomic effects associated to drought due to water availability limitations.
ID: DM N 10	Drought preparedness network for the Mediterranean	x	x			Collection and analysis of information on drought and drought mitigation Carry out Drought Identification, Risk Analysis, and Best Practices on six partner countries Develop guidelines for drought preparedness plans with the participation of institutional and civil stakeholders Verify and test Drought Guidelines on six different partner water basins Disseminate Guidelines as model to Mediterranean countries for formulating their own plans Set up the framework for a Drought Preparedness Network for the Mediterranean countries

7.2.5.2 Zimbabwe

Both state of the art and African (Zimbabwe) drought monitoring institutions use both in situ and satellite based tools or methods to capture input data. Zimbabwean organisations mainly use in situ methods whereas those in Europe or America use satellite based data e.g. Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA-7, 9, 11, 14, 16 and 18 afternoon polar-orbiting satellites Input data for Zimbabwe is inadequate as can be seen by spatial variation of forecasts .Moreover since input data is obtained in situ; other areas are not adequately covered due to inadequate equipment. The comparison is shown in **Table 23**.

Table 23: Comparison of monitoring input data

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	:Zimbabwe	
SADC Drought Monitoring Center/SARCOF and Drought Management Centre for South-Eastern Europe (DMCSEE)	**Accuracy**			Both systems are relatively accurate as they use almost similar input methods (satellite based data)
	Purpose		Monitor floods	Monitoring and assessment of drought risks and vulnerability
	Input data	Meteorological data (GPCC data)	Meteorological data	
	adequacy	Good	Fair	
Meteorological Services Department (Zimbabwe) and Australia Bureau of Meteorology	**Accuracy**	Very good	Fair	
	Purpose			Monitoring, Forecasting, warning, response
	Input data	BoM & SILO gridded weather data, US MODIS, ESA AATSR, AVHRR	Meteorological data fusing in both situ and satellite based methods. More bias towards in situ input data	

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	:Zimbabwe	
	adequacy		inadequate	
ZINWA and Water Information Research and Development Alliance	**Accuracy**	accurate	Fairly accurate	
	Purpose		planning, coordination, management of water resources and the delivery of water	Monitoring, forecasting
	Input data	BoM & SILO gridded weather data, US MODIS, ESA AATSR, AVHRR	In situ hydrological data.	
	adequacy	Fairly adequate	Limited input data; Unvailabilty of advanced data input technology	
AGRITEX in collaboration with NEWU and FAO and Managing Climate Variability/ Climate Kelpie	**Accuracy**	accurate	fair	
	Purpose		Assessment of vulnerability status	warning, response
	Input data		Food security data;	

7.2.6 West Africa - Mali

Table 24 shows comparison of available monitoring input data generated in Globally, Europe and Mali. The meteorological data the is available is mainly used as an input data to the models available for drought monitoring, this is found in globally, Europe and also in Mali. Hydrological data is mainly used in European countries as historical data is readily available

Table 24: Comparison of monitoring input data

ID	Institution	Output				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
AFRICA						
	Meteo Mali and Meteo France	x	x			Climate variability (wind speed, direction, temperature and insulation)
	AGRHYMET/ PRESAO Nationale Directorate of Hydrology					Water height, time of flood wave propagation from upstream to downstream (Mopti and Koulikoro)
	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	x			x	Early Warning System (SAP)
	The information comes from AGRHYMET and the National Directorate of Hydrology.		x			Prediction System of Information and Early Warning on flood of the Niger Delta (SPIAC)
GLOBAL						
ID: DM N 01	National Australia Bureau of Meteorology	x	x	x		Provides access to water and climate information: monitoring and forecast data, satellite data access to warnings and outlooks
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation		x			Collaborates with the Bureau of Meteorology

ID	Institution	Output				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
ID: DM N 03	Managing Climate Variability			x		An important outcome for drought management and forecasting is Climate Kelpie
ID: DM N 04	Australian Water Availability Project				x	(rainfall, solar radiation, maximum and minimum temperature) from the Bureau of Meteorology
ID: DM N 05	Water Information Research and Development Alliance General information					Water balance reporting
ID: DM N 06	Climate Kelpie					A database which uses a small form at the top of the screen to search for records. The searcher can choose a region of interest, the commodity of interest and the topic of interest. Topics are: 'managing climate', 'see forecasts', 'understand climate' and 'ask a farmer'
ID: DM N 07	National Drought Mitigation Center	x				U.S. Drought Monitor Daily Gridded SPI Climate Division SPI US rain vs dry days VegDRI VegOut (vegetation Outlook) GRACE-based Water Storage Drought Impact Reporter
ID: DM N 08	National Weather Service	x	x	x		Temperature & Precipitation (6-10-day, 8-14-day. One month, 3 months) U.S. Hazards Outlook (3-7 day, 8-14 day, contours)
ID: DM N 09	National Climatic Data Center	x		x		Climate Division Standardized SPI Vegetation Health products via STAR – Center for Satellite Applications and Research
ID: DM N 10	High Plains Regional Climate Center	x				Summary maps of daily gridded SPI in collaboration with the NDMC.
ID: DM N 11	Department of Agriculture, Natural Resources	x				Surface Water Supply Index – SWSI

ID	Institution	Output				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
	Conservation Service					
ID: DM N 12	Bureau of Reclamation	x		x		Produces daily tabular data for other water systems and real-time reservoir teacup diagrams
ID: DM N 13	Bureau U.S. Army Corps of Engineers				x	Outputs and methods differ for different regional organisations
ID: DM N 14	National Aeronautics and Space Administration	x				Water storage assessments based on Satellite imagery like MODIS, GRACE etc.
ID: DM N 15	Geological Survey	x			x	WaterWatch & Drought watch - http://waterwatch.usgs.gov/ EROS Drought http://eros.usgs.gov/#/Science/Climate_Change/Drought VegDri - http://vegdri.cr.usgs.gov/viewer/viewer.htm
ID: DM N 16	University of Washington		x			Variable Infiltration Capacity (VIC)
ID: DM N 17	USFS Wildland Fire Assessment System	x	x			NDVI Greenness Keetch-Byram Drought Index Palmer Index
EUROPE						
ID: DM N 01	European Drought Observatory	x	x			Assessing, monitoring and forecasting droughts on a continental level
ID: DM N 02	Drought Management Centre for South-Eastern Europe	x	x			-Air temperatures and surface water balance -SPI -Fraction of Vegetation Cover
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations, Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x				Daily Gridded SPI Climate Division SPI

ID	Institution	Output				Remarks
		Monitoring data	**Forecast data**	**Satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
ID: DM N 05	System of Prediction and Management of Droughts	x			x	Enables managers and users of water resources with an instrument that allows the anticipation of the potential impacts of drought situations, in order to promote the implementation of mitigation measures.
ID: DM N 06	The Drought Bulletin	x				The regional drought bulletins are provided by different entities based on monthly SPI
ID: DM N 07	Drought evaluation - Environment Agency	x				Ensures that water companies have effective plans in place to maintain public water supplies during a drought without damaging the environment
ID: DM N 08	Integrated project on water and global change				x	Brings together hydrological, water resources and climate communities
ID: DM N 09	XEROCHORE	x	x	x	x	Exploration of hydro climatic aspects of drought, propagation of meteorological droughts into hydrological droughts, integrated drought assessment framework (hydrology and climate), drought monitoring (incl. early warning) and forecasting
ID: DM N 10	Drought preparedness network for the Mediterranean	x				- Drought management Guidelines. Paper, website and CD versions -Tutorial of the Drought Management Guidelines. Website and CD -Technical Annexes of the Drought Management Guidelines

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7.3 COMPARATIVE ANALYSIS OF FRAMEWORK CONDITIONS - RESOURCING

7.3.1 North Africa – Algeria, Morocco and Tunisia (Maghreb Region)

As we mentioned in the previous point, drought monitoring in North-Africa is achieved by institutions or ministerial departments but none of them (excepting the national drought Observatory in Morocco) is especially oriented towards drought or have a special unit or cell dedicated to drought monitoring. In additional they all have a national or sub-national coverage. It is therefore very difficult to assess and evaluate how they are resourced in terms of financial and human resources and compare them with the "state of the art drought monitoring systems" which are regional systems (European systems) or national systems developed in large countries such as the United-States or Australia.

In Morocco, in terms of infrastructures and human capacities, the Met Office (DMN) is fully equipped to monitor Meteorological drought. The Royal Centre for Remote Sensing (CRTS) is also fully equipped with hardware, software and staff to produce tools for drought monitoring. The Ministry of Agriculture has full capacity of trained human resources to survey emerging drought impacts in the field and is therefore oriented towards agricultural drought monitoring. The Ministry also has the capacity to link agricultural drought with socio-economic drought categories through field surveys of evolving commodity prices. The ministry of Water through the river basin agencies has infrastructure capabilities to measure water levels fluctuations, underground and in the reservoirs, that could reflect the potential hydrological drought situations of the country (Ameziane, GDIEWS questionnaire). Thus, each of these institutions monitor a specific type of drought (meteorological, hydrological, agricultural or socio-economic) but there is no functional entity that coordinates and compiles all those drought information in one single product. That was in fact the objective of the national Drought Observatory that was created in 2001 as a coordinating structure and also as a link between the scientific community working on various drought issues and the decision makers in charge of drought management activities. The National Drought Observatory was designed to operate as an institutional network with a central management unit and regional sub-units, the whole system benefiting from existing structures, particularly the existing scientific human resources, both centrally and regionally. The central management unit of the NDO was located in Rabat in order to be close to the central units of the key ministerial departments and institutions in charge of drought and water resources management. Like other drought observatories in the world and namely the US Drought observatory which supported its creation, the NDO was based at the Institut Agronomique et Vétérinaire Hassan II (IAV Hassan II) in a scientific and technical environment that guarantees its independence and efficiency.

Unfortunately, due to a lack of funding and a lack of legal institutional framework of cooperation between institutions in charge of monitoring networks and the NDO, it did not succeed to achieve its goals.

7.3.2 Equatorial Lakes Region

7.3.2.1 Kenya

The project uses Geographic Information System (GIS) mapping with open-source data. Villagers have been trained to use mobile phones to record information about water levels and the number of households and specific livestock - camels, donkeys, cattle, sheep or goats - using particular waterholes.

These data are combined with satellite images generated by the US National Aeronautics and Space Administration (NASA) to identify water sources, which are then visited by monitoring staff to ensure that water is present.

"We want to look at the conditions, the water quality, and distance trekked by livestock to a waterhole, as well as the forage conditions in the region," said Joseph Matere, an FAO official in Nairobi, Kenya's capital.

The data from locals on the ground and from NASA are fed into a computer that models the topography of the region along with hydrological characteristics such as infiltration, evapo-transpiration and surface run-off, explained MacOpyio.

The computer generates colour-coded images of the land. Green indicates normal vegetation cover; yellow suggests that the vegetation is getting poor, while brown means that it is scarce.

"Yellow areas ... imply that long-term vegetation conditions are 20 to 40 percent below normal, which points toward drought conditions,"

The aim is to come up with "a very reliable early warning system" and to give pastoralists faced with water shortages ideas on how to cope with drought conditions.

Computer models could also reproduce historical data, showing water conditions in years past. This could help scientists forecast conditions more accurately over periods ranging from three months to five years.

"This water monitoring system is very useful because it gives specific information on water and drought conditions of a specific area," said Elizabeth Lokolio, a livestock officer with a Turkana pastoralist organization. She was trained as one of the project's drought monitors.

Lokolio said that that the new method of communicating about water conditions is far superior to traditional practices, which relied on village elders to report information.

As part of the program, forecasts and advice are communicated to Turkana pastoralist communities via the Internet - accessed in part on mobile phones - but MacOpiyo said that scientists hope to work with the National Drought Monitoring Authority to disseminate their forecasts through community radio, text messaging and community meetings as well.

The pilot project in Turkana ended in February of this year, and now seeking FAO funding to support its continuation and expansion into other arid and semi-arid parts of the country.

7.3.2.2 Rwanda and Burundi

Rwanda Meteorological Service and Burundi National Meteorological and Hydrological Service are fully governmental funded institutes. Monitoring is mainly done by these institutes with collaboration of other regional service which may intervene in data sharing, capacity building or funding specific projects. Resources (human and technical) are still to be increased if we compare with other countries like USA, Australia, Europe, etc., where many institutes are involved in drought monitoring and forecasting, with more resources (human, technical and technological resources).

7.3.3 Eastern Nile Region (Downstream countries)

7.3.3.1 Comparative analysis - Egypt

Table 25 compares resources for monitoring and early warning systems in Egypt to "state of the art".

Table 25: Monitoring and Forecasting Systems in Regional and other systems relevant to Africa (Resource)

System_ID	Resources	Similarities	Differences	System Level
DM-R01 To DM-R08	Exchanging the experts within the region. International financial support	Transfer technology. Considering the resources of the region.	Type of application, experience exchange	*Regional system*
DM-AC01 to DM-AC03	External experiences, global data sets, technology, level of application	Regional application, water resources management	Level of application, qualified human resources	*Africa Continental*
DM-NNA01 to DM-NNA13	International experiences, global data sets, technology applied	Constructing a database consider as a support for a n early warning system	Infrastructure, professional human resources	*Northern Africa*

System_ID	Resources	Similarities	Differences	System Level
DM-NEA01 to DM-NEA08	Well experience, financial support	Financial Recourses and technical experience required	Technology applied level	*Eastern Africa*
DM-NSA01 to DM-NSA03	Experts , technology, financial support	Technical experience required	Technology applied based on the application developed	*Southern Africa*
DM-NWA01 to DM-NWA05	Experts technology, financial support	Building capacity, different level of experts		*Western Africa*
DM-ENA01 to DM-ENA04	Experts technology, financial support	Building capacity,	infrastructure, technology	*Europe and North Africa*
DM-EAC01 to DM-EAC03	Experts technology, financial support			*Europe and Continental Africa*

7.3.3.2 Sudan

Table 26 compares resources for monitoring and early warning systems in Sudan to "state of the art".

Table 26: Comparison of globally available state-of-the-art drought monitoring systems with those in use in Sudan

ITEM	GLOBALLY	AFRICA / Sudan
PURPOSE	Monitor changes and its impacts; Update forecasts to provide users with first-hand climate and water supply assessments through products and also to link to other sites that provide information on snow pack, soil/crop moisture conditions, ground water and reservoir levels, stream flow, fire danger, and seasonal forecasts. Ease access to the information and forecasting messages through the Internet and the web sites, users could assemble the necessary data and information to assess current climate conditions and longer-range climate and water supply outlooks.	Monitor the weather parameters, and produce seasonal forecast and monitor the changes in climate conditions and its impacts on the vegetation cover
TOOLS	• Satellite images • Radar • Real time weather stations • Automatic weather stations • Utilize multiple climate indices and indicators to assess drought conditions. • Integrates multiple drought indicators with field information and expert input • Geographic Information Systems (GIS) • supercomputing capabilities	• Real time rainfall data, • Historical data • Satellite images • Sudan Agricultural monitoring information System (SAMIS) • PRECIS model • Numerical and statistical packages (EAT, MM5, WFR) • local knowledge use by the local communities as tool for drought forecasting

	• Decision Support systems and sophisticate Models and software	
MONITORING FREQUENCY	24 hours	24 hours
DATA CAPTURED	• Marine data: sea surface temperature, water temperature, wind, rainfall, solar radiation, pressure • Airport data: Temperature, wind direction, wind speed, solar radiation, rainfall, air pressure • Cloud imagery • NDVI	• Temperature (minimum & maximum), wind direction, wind speed, solar radiation, rainfall, air pressure, sun shine hours, relative humidity, evaporation • Cloud imagery (CCD) from IGAD& ICPAC, WMO • NDVI (FAO website) •
HUMAN CAPACITY REQUIREMENT	Highly skilled meteorologists, modelers, physics scientists, meteorologist technician	Meteorologists, agro-meteorologist, meteorologist technician
COST	High	Low investment

7.3.4 Southern Africa

7.3.4.1 South Africa

Table 27 compares resources for monitoring systems in South Africa to “state of the art”.

Table 27: Comparison of available monitoring resources

Action	Global	Europe	Limpopo(South Africa)
Funding for research programmes on:			
• Water resources assessment	x		x
• Hydrological modelling	x	x	x
• Water accounting	x		
• Data compatibility and sharing system	x		
Information and links to other websites	x	x	
Collaboration with other institutions/partners (NASA, NOAA, USGS, WMO,UN etc.) for:	x	x	
• Climate based monitoring	x	x	
• GI Science and analysis (researching ways to use data from satellites and other remote sensing devices to measure drought)	x		
• Planning and social science			
Distribution of centres around the country:			
• Basin Authority		x	
• Headquarters	x	x	
• Regional support centres	x	x	
• River forecast centres		x	
• National centres	x	x	x

• Climate centres		x	
• Workforce/extension officers	x	x	x
Available Skills:			
• Scientists	x	x	x
• Technicians	x	x	x
• Support staff	x	x	
Capacity building	x	x	x
Availability of network stations	x	x	
Dissemination of information (internet, television, newspapers, email, bulletins etc)	x	x	x

Table 27 compares resources for monitoring systems in South Africa to "state of the art".

Table 27 shows comparison of available monitoring resources Globally, Europe and South Africa. These are:

- Research funding programmes
- Collaboration of institutions
- Distribution of centres around the country
- Available workforce
- Available network stations
- Capacity Building
- Systems to disseminate information

There is emphasis into research for monitoring of drought globally and Europe even though there is an improvement in South Africa. Institutions collaborate to combine skills available thus improving the quality of the product. The centres are distributed through the country for collection of data and dissemination of available information. This information in disseminated through internet, television, radio newspapers and bulletin. More skilful people are needed in Africa for research programmes that are made available and for analysis and interpretation of information

7.3.4.2 Zimbabwe

Table 28 shows a few selected key organisations from Zimbabwe and their sources of funding.

Table 28: Key organisations and sources of funds

Organization	Source of funds
AGRITEX(NEWU);FAO	Government, UN
Meteorological Services Department of Zimbabwe(MSD)	Government
Zimbabwe National Water Authority(ZINWA)	Government; Donor

SADC DMC	SADC;WMO;UNDP;
SARCOF	SADC

Table above shows that local organisations receive funding mainly from government and they are governmental affiliated institutions; whereas for state o the art they are a few governmental institutes. Moreso the funds for these local institutions are very little and limited and some projects are done in conjunction with Non-governmental organisations (NGOs).

7.3.5 West Africa - Mali

7.3.6 West Africa

Table 27 compares resources for **monitoring systems in** South Africa to "state of the art".

Table 27 shows comparison of available monitoring resources Globally, Europe and Mali in terms of the following attributes:

- Research funding programmes
- Collaboration of institutions
- Distribution of centres around the country
- Available workforce
- Available network stations
- Capacity Building
- Systems to disseminate information

Table 29: Comparison of available monitoring resources

Action	Global	Europe	Mali (West Africa)
Funding for research programmes on:			
• Water resources assessment	X		X
• Hydrological modelling	X	X	
• Water accounting	X		
• Data compatibility and sharing system	X		
Information and links to other websites	X	X	
Collaboration with other institutions/partners (NASA, NOAA, USGS, WMO,UN etc.) for:	X	X	
• Climate based monitoring	X	X	

• GI Science and analysis (researching ways to use data from satellites and other remote sensing devices to measure drought)	X		
• Planning and social science			
Distribution of centres around the country:			
• Basin Authority		X	
• Headquarters	X	X	
• Regional support centres	X	X	
• River forecast centres		X	X
• National centres	X	X	X
• Climate centres		X	
• Workforce/extension officers	X	X	X
Available Skills:			
• Scientists	X	X	
• Technicians	X	X	
• Support staff	X	X	
Capacity building	X	X	
Availability of network stations	X	X	X
Dissemination of information (internet, television, newspapers, email, bulletins etc)	X	X	X

7.4 THE MAIN CHALLENGES ON MONITORING DROUGHTS IN ARICA

Some of the most major challenges to monitoring of drought in Africa are as follows:

(i) meteorological and hydrological data networks are often 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;

(ii) data sharing is inadequate between government agencies and research institutions

(iii) 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 for if the data is required by education and research institutions;

(iv) information delivered through early warning systems, when it does exist on an occasion basis, is often too technical, limiting its use by decision makers and farmers;

(v) forecasts, when they exist on an occasion basis, are often unreliable on the seasonal timescale and lack specificity, reducing their usefulness for agriculture and other sectors;

(vi) impact assessment methodologies, a critical part of drought monitoring and early warning systems, are not standardized or widely available, hindering impact estimates and the creation of regionally appropriate mitigation and response programs;

(vii) delivery systems for disseminating data to users in a timely manner are not well developed or inexistent, limiting their usefulness for decision support;

(viii) drought indices are sometimes inadequate for detecting the early onset and end of drought;

(ix) poor integration of information into government structures and

(x) focus on emergency response rather than long-term planning.

Political enthusiasm for early warning system tends to be high in the aftermath of a drought but usually steadily declines over time.

Table 30 summarises the main shortcomings of current North-African drought early warning systems:

Table 30: The main shortcomings of current North African drought early warning systems

Main shortcomings of current drought early warning systems	Current status
Data networks	Inadequate density and data quality of meteorological and hydrological networks and lack of data networks and databases on all major climate and water supply parameters.
Data sharing	Inadequate data sharing between government agencies and the high cost of data limit the application of data in drought preparedness, mitigation, and response.
Early warning system products	Data and sparse information products are often not user friendly and users are often not trained in the application of this information to decision

Main shortcomings of current drought early warning systems	Current status
	making.
Drought forecasts	Unreliable seasonal forecasts and the lack of specificity of information provided by forecasts limit the use of this information by farmers and others.
Drought monitoring tools	Inadequate or absence of indices for detecting the early onset and end of drought, although the Standardized Precipitation Index (SPI) was cited as an important new monitoring tool to detect the early emergence of drought.
Integrated drought/climate monitoring	Drought monitoring systems should be integrated and based on multiple indicators to fully understand drought magnitude, spatial extent, and impacts.
Drought impact assessment methodology	Lack of impact assessment methodology hinders impact estimates and the activation of mitigation and response programs.
Delivery systems	Data and information on emerging drought conditions, seasonal forecasts, and other products are often not delivered to users in a timely manner.

8 COMPARISON OF GLOBALLY AVAILABLE STATE-OF-THE-ART DROUGHT EARLY WARNING SYSTEMS AND THOSE IN USE IN AFRICA

Besides the meteorological services that provide seasonal forecasts presented in deliverable D2.3, there are no other current drought forecasting activities in North Africa. It is therefore possible to do the comparison with the “state of the art” forecasting systems according to the framework diagram presented in **Figure 3**.

8.1.1 North Africa – Algeria, Morocco and Tunisia (Maghreb Region)

It is probably due to the fact that many researchers and especially agronomists consider that drought in the Mediterranean area can only be monitored and not predicted. Thus, current drought prediction capabilities as to set up ***onset, persistence, and end of a drought*** are still at a modest level and a lot of research-action is still needed to proceed forward with drought forecasting in the agricultural sector of the Mediterranean and the Near East Region. However, substantial body of good information and knowledge is available to serve as the basis for capacity development in drought preparedness, mitigation and response. The World Meteorological Organization could play a decisive role for sharing information and good practices for drought early warning as generated by the WCRP (Ameziane, GDEWS questionnaire, 2010).

There has been an international effort to use climate information for practical applications in early warning system. If appropriately developed, **seasonal climate forecasts** can help concerned stakeholders, such as farmers and agricultural planners, make proactive decisions on seasonal agricultural strategies (e.g., planting schedules, fertilizer distribution, weeding, and seed choice), future food and marketing needs, and further allocations of grazing areas for livestock.

Information on possible droughts and disasters will help government officials, donors, and NGOs to prepare and allocate adequate resources to alleviate the potential problem.

The ability to broadcast drought early warning information has been improved by new technologies such as automated weather stations, improved satellite observations, advanced computing technology, and improved communication techniques. This allows scientists and planners to further improve drought monitoring tools at local, national, and regional scales. The tools could make available improved drought related vegetation condition assessments and predictions to collectively analyze climate data from station networks that have increased spatial and temporal coverage and satellite based earth observations that are now readily available at minimal cost. If such drought monitoring tools become part of a comprehensive early warning system, they can provide decision makers with improved and timely information.

An early warning system using improved drought monitoring tools can trigger timely and appropriate preventive measures if the country has adequate institutional capacity to communicate and implement recommendations.

8.2 COMPARATIVE ANALYSIS OF FRAMEWORK CONDITIONS - OUTPUTS

In this section the main similarities and differences on outputs are highlighted. The analysis considers how the outputs relate to the user requirements described in Chapter 5.

8.2.1 Equatorial Lakes Region

8.2.1.1 Kenya

The prediction products are provided through outlooks for a decade, month and season. Consensus pre-season climate outlook which are also organised in conjunction with the major climate centres world-wide in order to derive a single consensus forecast for the region.

8.2.1.2 Rwanda and Burundi

Drought forecast in Rwanda and Burundi is disseminated through media (Radio, TV and printed media). Bulletins are also published every month. Users can then be informed about the weather predictions. In order to be more reliable, weather forecast needs to be empowered and ensure more access to local people in order improve preparedness to some weather severities. The data and information flows are illustrated in **Figure 6**.

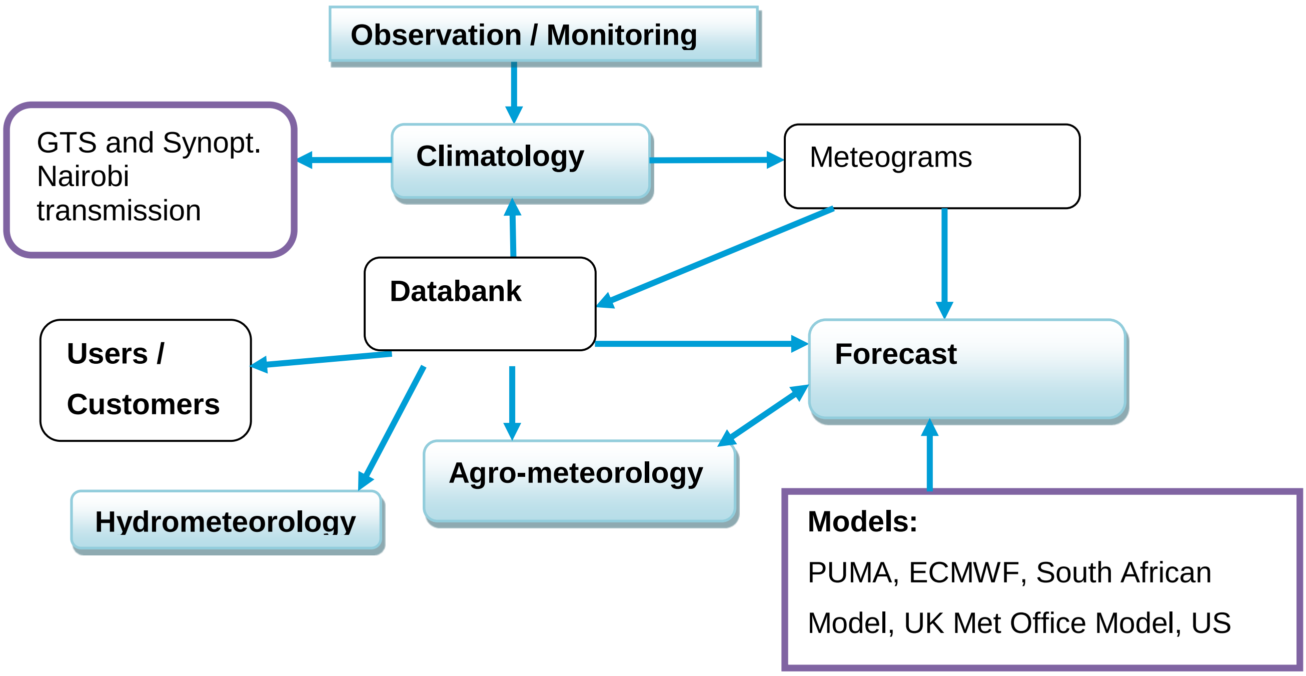

Figure 6: Data and information flow

Source: Rwanda Meteorological Service

The main difference in drought monitoring and forecasting between RMS and globally available technology is the luck of weather RADAR and upper air weather stations. Therefore, the forecast rely on imported models and additional satellite data which are collected at inappropriate resolution for a small country like Rwanda.

8.2.2 Eastern Nile Region (Downstream countries)

8.2.2.1 Comparative analysis - Egypt

Table 31 compares output data for early warning systems in Egypt to "state of the art".

Table 31: Forecasting Systems in Regional and other systems relevant to Africa (Output)

System_ID	Output data	Similarities	Differences	System Level
DM-R01 to DM-R08	Meteorological maps, reports and Bulletin	Information type and frequency	Spatial resolution	*Regional system*
DM-AC01 to DM-AC03	Meteorological maps, Meteorological Information, reports and Bulletins	Information type and frequency	Spatial resolution	*Africa Continental*
DM-NNA01 to DM-NNA13	Spatial information presentation	Applied advanced technology		*Northern Africa*
DM-NEA03, DM-	Metrological Bulletin, Reports	The system applied	Indicators	*Eastern Africa*

System_ID	Output data	Similarities	Differences	System Level
NEA04, DM-, NEA06	and Maps	at a pilot areas not considering all over the country	and level of accuracy	
DM-NSA01, DM-NSA03	National policy for drought and flood adaptation and mitigation measures	The system applied at a pilot areas not considering all over the country	Technical analysis approach	*Southern Africa*
DM-NWA02, DM-NWA03, DM-NWA04	National strategy for drought and adaptation measures			*Western Africa*
DM-ENA04				*Europe and North Africa*
DM-EAC01 to DM-EAC03				*Europe and Continental Africa*

8.2.2.2 Sudan

The drought forecasting system in Sudan is for early warning and forecast predications tools. There is limited regional cooperation, and limited capacity of individual forecasting institutes and governmental bodies, also there is limited access to climate downscaling model and other software.

One the SMA product is monthly bulletin was issued and disseminated to policy makers and stakeholders and it is available online for public use. Also SMA provides:

- Maps of rainfall estimate and its derivatives (accumulation, difference from average, percentage of average, total amounts on dekadal, monthly & seasonal bases.
- Number of dry & wet days within each dekadal.
- Start of growing season.
- Maps of NDVI and its derivatives (maximum, difference from average, as a percentage of average).

8.2.3 Southern Africa

8.2.3.1 South Africa

Table 32 shows comparison of available forecasting output data generated in Globally, Europe and South Africa. The main similarities are that the countries produce meteorological data for use. Countries in Europe and globally use remote sensing to get satellite data and it available to users who may need it whilst in South Africa it is not the case. South Africa produces only the Standardized Precipitation Index for the use in drought monitoring whilst there are a lot of other drought related indices that are produced globally and in Europe.

Table 32: Comparison of forecasting output data

ID	Institution	Output				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
			AFRICA			
ID: DM R 06	SARCOF	x	x			Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season
ID: DM N 08	SAWS	x	x	x		Meteorological bulletins, average seasonal temperatures and accumulated precipitations for the season, SPI
ID: DM R 07	FEWSNET	x	x			Rainfall, moisture index, land use , Elevation
	Department of Water Affairs	x			x	Department of Water in South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and taking into consideration upstream developments. In general drought warnings are issued after assessing the availability of water on the dams against the total allocations to users. The same approach for annual water allocation is applied with the lowest historical inflow and different allocations to irrigation farmers.
	FARMERS ASSOCIATIONS		x		x	• Impose self-restrictions among themselves to try and manage allocation. This is done by restricting themselves to 50% of their allocation. • If the dam overflows or is above 95% every month – receive 100% allocation • After end July every farmers gets 70% of his allocation • Have employed a water bay leaf – this person does physical inspection of rivers and stream along the farms. This is to check their levels so that a decision can be made on time in-terms of water availability

ID	Institution	Output				Remarks
		Monitoring data	**Forecast data**	**Satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
						A technical committee has been put in place comprising of Mr Jackie Venter (DWA), MR Andre Venter (Letaba Water Users Association), South African Weather Services and Accu weather information.
				GLOBAL		
ID: DM N 01	National Australia Bureau of Meteorology	x	x	x		Provides access to water and climate information: monitoring and forecast data, satellite data access to warnings and outlooks
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation		x		x	Collaborates with the Bureau of Meteorology
ID: DM N 03	Managing Climate Variability			x	x	An important outcome for drought management and forecasting is Climate Kelpie
ID: DM N 04	Australian Water Availability Project				x	(rainfall, solar radiation, maximum and minimum temperature) from the Bureau of Meteorology
ID: DM N 05	Water Information Research and Development Alliance General information				x	Water balance reporting
ID: DM N 06	Climate Kelpie					A database which uses a small form at the top of the screen to search for records. The searcher can choose a region of interest, the commodity of interest and the topic of interest. Topics are: ‘managing climate’, ‘see forecasts’, ‘understand climate’ and ‘ask a farmer’
ID: DM N 07	National Drought Mitigation Center	x				U.S. Drought Monitor Daily Gridded SPI Climate Division SPI

ID	Institution	Output				Remarks
		Monitoring data	**Forecast data**	**Satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
						US rain vs dry days VegDRI VegOut (vegetation Outlook) GRACE-based Water Storage Drought Impact Reporter
ID: DM N 08	National Weather Service	x	x	x		Temperature & Precipitation (6-10-day, 8-14-day. One month, 3 months) U.S. Hazards Outlook (3-7 day, 8-14 day, contours)
ID: DM N 09	National Climatic Data Center	x		x		Climate Division Standardized SPI Vegetation Health products via STAR – Center for Satellite Applications and Research
ID: DM N 10	High Plains Regional Climate Center	x				Summary maps of daily gridded SPI in collaboration with the NDMC.
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	x			x	Surface Water Supply Index – SWSI
ID: DM N 12	Bureau of Reclamation	x		x	x	Produces daily tabular data for other water systems and real-time reservoir teacup diagrams
ID: DM N 13	Bureau U.S. Army Corps of Engineers					Outputs and methods differ for different regional organisations
ID: DM N 14	National Aeronautics and Space Administration	x			x	Water storage assessments based on Satellite imagery like MODIS, GRACE etc.
ID: DM N 15	Geological Survey	x			x	WaterWatch & Drought watch - http://waterwatch.usgs.gov/ EROS Drought http://eros.usgs.gov/#/Science/Climate_Change/Drought VegDri - http://vegdri.cr.usgs.gov/viewer/viewer.htm
ID: DM N 16	University of Washington		x			Variable Infiltration Capacity (VIC)

ID	Institution	Output				Remarks
		Monitoring data	**Forecast data**	**Satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
ID: DM N 17	USFS Wild land Fire Assessment System	x	x			NDVI Greenness Keetch-Byram Drought Index Palmer Index
EUROPE						
ID: DM N 01	European Drought Observatory	x	x			Assessing, monitoring and forecasting droughts on a continental level
ID: DM N 02	Drought Management Centre for South-Eastern Europe	x	x			-Air temperatures and surface water balance -SPI -Fraction of Vegetation Cover
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations, Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x				Daily Gridded SPI Climate Division SPI
ID: DM N 05	System of Prediction and Management of Droughts	x				Enables managers and users of water resources with an instrument that allows the anticipation of the potential impacts of drought situations, in order to promote the implementation of mitigation measures.
ID: DM N 06	The Drought Bulletin	x				The regional drought bulletins are provided by different entities based on monthly SPI
ID: DM N 07	Drought evaluation - Environment Agency	x			x	Ensures that water companies have effective plans in place to maintain public water supplies during a drought without damaging the environment
ID: DM N 08	Integrated project on water and global change				x	Brings together hydrological, water resources and climate communities
ID: DM N 09	XEROCHORE	x	x	x	x	Exploration of hydro climatic aspects of drought,

ID	Institution	Output				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
						propagation of meteorological droughts into hydrological droughts, integrated drought assessment framework (hydrology and climate), drought monitoring (incl. early warning) and forecasting
ID: DM N 10	Drought preparedness network for the Mediterranean	x				- Drought management Guidelines. Paper, website and CD versions -Tutorial of the Drought Management Guidelines. Website and CD -Technical Annexes of the Drought Management Guidelines

The data released is mainly for the Southern region whilst coverage for European and global institutions is wider. The is less output of the river/stream flow data in South Africa as compared to other European countries. Hydrological droughts South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and farmers uses self-imposed restrictions among themselves to try and manage allocation. This is done by restricting themselves to 50% of their allocation and also physical inspection of rivers and stream along the farms for agricultural droughts.

8.2.3.2 Zimbabwe

Table 33 compares output data for early warning systems in Zimbabwe to “state of the art”.

Table 33: Comparison of forecasting output data

<table>
<tr><th rowspan="2">Organisations/Institutions being compared</th><th rowspan="2">Aspect of comparison</th><th colspan="2">Differences</th><th rowspan="2">Similarities</th></tr>
<tr><th>State of the Art: Europe /US</th><th>:Zimbabwe</th></tr>
<tr><td rowspan="4">SADC Drought Monitoring Center and Drought Management Centre for South-Eastern Europe (DMCSEE)</td><td>Coverage</td><td></td><td></td><td>Both are Regional and cover large areas, which combined several countries. SADC DMC , covers southern Africa and DMCSEE covers South –eastern Europe</td></tr>
<tr><td>Frequency</td><td>Maps are updated twice per month. Final data maps with two months delay are available after 20th day of the current month. First-guess maps are available after 5th day of the next month.</td><td>Generate medium-range (10-14 days) and long-range climate outlook products on monthly and seasonal (3-6 months) timescales.</td><td>Frequency is almost similar</td></tr>
<tr><td>Purpose</td><td></td><td>monitor floods</td><td>Monitoring and assessment of drought risks and vulnerability</td></tr>
<tr><td>Output data</td><td></td><td></td><td>Both provide Drought Monitoring bulletins and maps</td></tr>
<tr><td rowspan="4">Meteorological services Department (Zimbabwe) and Australia Bureau of Meteorology</td><td>Coverage</td><td></td><td></td><td>Both provide national coverage</td></tr>
<tr><td>Frequency</td><td>For most parameters the time periods are: Day, week, month, 3months, 6months, 12monhths</td><td>Day;5 day; monthly and seasonal forecasts</td><td></td></tr>
<tr><td>Purpose</td><td></td><td></td><td>Monitoring, Forecasting, warning, response</td></tr>
<tr><td>Output data</td><td>- weekly rainfall update
- Seasonal rainfall outlooks
- Seasonal Temperature outlooks
- Seasonal Streamflow Forecasts
- Climate statements archive</td><td>Rainfall; temperature; atmospheric pressure; wind forecast data. satellite images and outlook maps.</td><td>Little or less provision of stream flow, runoff and hydrological data.</td></tr>
</table>

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	:Zimbabwe	
ZINWA and Water Information Research and Development Alliance	**Coverage**	National Level (Australia)	National (Zimbabwe)	
	Frequency		Weekly and seasonal	
	Purpose		planning, coordination, management of water resources and the delivery of water	Monitoring, forecasting
	Output data	Precipitation and actual evaporation products, seasonal and short- and long-term water forecasting and prediction, Water information Models and water data transfer standards	Stream levels; runoff data. Evaporation data;	
AGRITEX in collaboration with NEWU and FAO and Managing Climate Variability/ Climate Kelpie	**Coverage**			National
	Frequency		Monthly; Seasonal	
	Purpose		Assessment of vulnerability status	warning, response
	Output data	a database providing access to weather and climate forecasts and projections at other institutes, mostly the Bureau of Meteorology	Crop assessment reports. Food security status	

8.2.4 West Africa - Mali

Table 34 shows comparison of available forecasting output data generated in Globally, Europe and Mali. The main similarities are that the countries produce meteorological data for use. Countries in Europe and globally use remote sensing to get satellite data and this is available to users who may need it. In Mali the data released is mainly for the southern region whilst coverage for European and global institutions is wider. There is less forecasting of the river/stream flow data in Mali as compared to other European countries.

Table 34: Comparison of forecasting output data

ID	Institution	Output				Remarks
		Monitoring data	**Forecast data**	**Satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
			AFRICA			
	Meteo Mali and Meteo France	x	x			Climate variability (wind speed, direction, temperature and insulation)
	AGRHYMET/ PRESAO Nationale Directorate of Hydrology					Water height, time of flood wave propagation from upstream to downstream (Mopti and Koulikoro)
	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	x			x	Early Warning System (SAP)
	The information comes from AGRHYMET and the National Directorate of Hydrology.		x			Prediction System of Information and Early Warning on flood of the Niger Delta (SPIAC)
			GLOBAL			
ID: DM N 01	National Australia Bureau of Meteorology	x	x	x		Provides access to water and climate information: monitoring and forecast data, satellite data access to warnings and outlooks
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation		x			Collaborates with the Bureau of Meteorology
ID: DM N 03	Managing Climate Variability			x		An important outcome for drought management and forecasting is Climate Kelpie

ID: DM N 04	Australian Water Availability Project				x	(rainfall, solar radiation, maximum and minimum temperature) from the Bureau of Meteorology
ID: DM N 05	Water Information Research and Development Alliance General information					Water balance reporting
ID: DM N 06	Climate Kelpie					A database which uses a small form at the top of the screen to search for records. The searcher can choose a region of interest, the commodity of interest and the topic of interest. Topics are: 'managing climate', 'see forecasts', 'understand climate' and 'ask a farmer'
ID: DM N 07	National Drought Mitigation Center	x				U.S. Drought Monitor Daily Gridded SPI Climate Division SPI US rain vs dry days VegDRI VegOut (vegetation Outlook) GRACE-based Water Storage Drought Impact Reporter
ID: DM N 08	National Weather Service	x	x	x		Temperature & Precipitation (6-10-day, 8-14-day. One month, 3 months) U.S. Hazards Outlook (3-7 day, 8-14 day, contours)
ID: DM N 09	National Climatic Data Center	x		x		Climate Division Standardized SPI Vegetation Health products via STAR – Center for Satellite Applications and Research
ID: DM N 10	High Plains Regional Climate Center	x				Summary maps of daily gridded SPI in collaboration with the NDMC.
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	x				Surface Water Supply Index – SWSI
ID: DM N 12	Bureau of Reclamation	x		x		Produces daily tabular data for other water systems and real-time reservoir teacup diagrams

ID: DM N 13	Bureau U.S. Army Corps of Engineers				x	Outputs and methods differ for different regional organisations
ID: DM N 14	National Aeronautics and Space Administration	x				Water storage assessments based on Satellite imagery like MODIS, GRACE etc.
ID: DM N 15	Geological Survey	x			x	WaterWatch & Drought watch - http://waterwatch.usgs.gov/ EROS Drought http://eros.usgs.gov/#/Science/Climate_Change/Drought VegDri - http://vegdri.cr.usgs.gov/viewer/viewer.htm
ID: DM N 16	University of Washington		x			Variable Infiltration Capacity (VIC)
ID: DM N 17	USFS Wildland Fire Assessment System	x	x			NDVI Greenness Keetch-Byram Drought Index Palmer Index
EUROPE						
ID: DM N 01	European Drought Observatory	x	x			Assessing, monitoring and forecasting droughts on a continental level
ID: DM N 02	Drought Management Centre for South-Eastern Europe	x	x			-Air temperatures and surface water balance -SPI -Fraction of Vegetation Cover
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations, Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x				Daily Gridded SPI Climate Division SPI
ID: DM N 05	System of Prediction and Management of Droughts	x			x	Enables managers and users of water resources with an instrument that allows the anticipation of the potential impacts of drought situations, in order to promote the implementation of mitigation measures.
ID: DM N 06	The Drought Bulletin	x				The regional drought bulletins are provided by different entities based on monthly SPI

ID: DM N 07	Drought evaluation - Environment Agency	x				Ensures that water companies have effective plans in place to maintain public water supplies during a drought without damaging the environment
ID: DM N 08	Integrated project on water and global change				x	Brings together hydrological, water resources and climate communities
ID: DM N 09	XEROCHORE	x	x	x	x	Exploration of hydro climatic aspects of drought, propagation of meteorological droughts into hydrological droughts, integrated drought assessment framework (hydrology and climate), drought monitoring (incl. early warning) and forecasting
ID: DM N 10	Drought preparedness network for the Mediterranean	x				- Drought management Guidelines. Paper, website and CD versions -Tutorial of the Drought Management Guidelines. Website and CD -Technical Annexes of the Drought Management Guidelines

8.3 COMPARATIVE ANALYSIS OF FRAMEWORK CONDITIONS - INPUTS

8.3.1 Equatorial Lakes Region

8.3.1.1 Kenya

In the drought prediction system for ICPAC use information on the state of the Sea Surface temperature anomalies over all the major ocean basins, surface and upper air anomalies of pressure, winds and other climate parameters.

8.3.1.2 Rwanda and Burundi

Regarding the inputs data, they are similarities of in-situ data collected from monitoring networks if we compare practices in Rwanda and in Burundi with state-of-the available monitoring systems (precipitation, evapotranspiration, wind speed and direction, soil moisture, etc.). However, the collection and flow of data in Rwanda and Burundi are mostly not automated compared to the state-of-the-art technologies. In addition, Additional data collected from other sources (RADAR and satellites) are sourced from outside and often without precision (low resolution compared to the small sizes of these countries Rwanda and Burundi.

8.3.2 Eastern Nile Region (Downstream countries)

8.3.2.1 Comparative analysis - Egypt

Table 35 compares input data for early warning systems in Egypt to “state of the art”.

Table 35: Forecasting Systems in Regional and other systems relevant to Africa (Inputs)

System_ID	Input data	Similarities	Differences	System Level
DM-R01 to DM-R08	Observed data, EO data, Global data sets, socio-economic data	Meteorological data, advanced technology applied, experimental research	Different users beneficiaries, level of accuracy, accuracy techniques	*Regional system*
DM-AC01 to DM-AC03	Observed data, EO data, Global data sets,	Water resources information, Meteorological data	Spatial data distribution, Frequency of input data, models applied	*Africa Continental*
DM-NNA01 to DM-NNA13	Meteorological data, Land use, EO data, Global data sets	Hydrological data, Meteorological data	System application, purpose of the system, technology applied	*Northern Africa*
DM-NEA03, DM-NEA04, DM-, NEA06	Meteorological data, Land use, EO data, Global data sets	All weather information	Level of application	*Eastern Africa*
DM-NSA01, DM-NSA03	Meteorological data, Land use, EO data, Global data sets	Meteorological data		*Southern Africa*
DM-NWA02, DM-NWA03, DM-	Meteorological data, Land use, EO data, Global data sets	Meteorological data, hydrological data		*Western Africa*

System_ID	Input data	Similarities	Differences	System Level
NWA04				
DM-ENA04		Meteorological data		*Europe and North Africa*
DM-EAC01 to DM-EAC03	Meteorological data, Land use, EO data, Global data sets, observed data		Spatial resolution, application level	*Europe and Continental Africa*

8.3.2.2 Sudan

The input data for drought monitoring and forecasting

- Temperature (minimum & maximum), wind direction, wind speed, solar radiation, rainfall, air pressure, sun shine hours, relative humidity, evaporation
- Cloud imagery (CCD) from IGAD& ICPAC, WMO
- NDVI (FAO website)

There are some constrain and challenges facing the SMA in acquiring the input data for forecasting which may be summarized in

- Dependency on one data provider.
- Low involving of end user in production and designing and justification.
- Engaging the end user in products verification.
- Establishing customer's network to ensure product verification and service feedback flow.
- Dissemination of information to end user in suitable format and in right time.
- Sustainability of data flow.
- Maintaining and troubleshooting of the system.

The needs in Sudan for effective forecasting systems are

- installation of new meteorological stations for data acquisition
- build capacity at all levels (researchers, meteorologists, technology transfer, farmers, policy makers, communities, etc) for effective interpretation and usage of forecasting messages
- Strategy for awareness rising at all levels.
- Improved data accessibility and exchange of forecast messages

8.3.3 Southern Africa

8.3.3.1 South Africa

Table 36 shows comparison of available forecasting input data generated in Globally, Europe and South Africa. The meteorological data the is available is mainly used as an input data to the models available for drought monitoring, this is found in globally, Europe and also in Africa. Hydrological data is mainly used in European countries as historical data is readily available. South Africa still has a challenge of capturing hydrological data as there are few records available. There is a decline on the meteorological stations in South Africa due to high maintenance of these stations.

Table 36: Comparison of forecasting input data

ID	Institution	Input				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
				AFRICA		
ID: DM R 06	SARCOF	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 08	SAWS	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM R 07	FEWSNET	x				Rainfall, moisture index, land use , Elevation
	Department of Water Affairs	x			x	Department of Water in South Africa uses storage trajectories to provide a constrained window of possible storage states based on stochastic analysis of inflows and taking into consideration upstream developments. In general drought warnings are issued after assessing the availability of water on the dams against the total allocations to users. The same approach for annual water allocation is applied with the lowest historical inflow and different allocations to irrigation farmers.
	FARMERS ASSOCIATIONS		x		x	• Impose self-restrictions among themselves to try and manage allocation. This is done by restricting themselves to 50% of their allocation.

ID	Institution	Input				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
						• If the dam overflows or is above 95% every month – receive 100% allocation • After end July every farmers gets 70% of his allocation • Have employed a water bay leaf – this person does physical inspection of rivers and stream along the farms. This is to check their levels so that a decision can be made on time in-terms of water availability A technical committee has been put in place comprising of Mr Jackie Venter (DWA), MR Andre Venter (Letaba Water Users Association), South African Weather Services and Accu weather information.
GLOBAL						
ID: DM N 01	National Australia Bureau of Meteorology	x				Climate variability (wind speed, direction, temperature and insulation)
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation	x		x		Different satellites provide this information.
ID: DM N 03	Managing Climate Variability	x				To improve communication between scientists and farmers. Same as Kelpie
ID: DM N 04	Australian Water Availability Project	x			x	Daily fields for rainfall, maximum and minimum temperature, continental observations of brightness temperature

ID	Institution	Input				Remarks
		Monitoring data	**Forecast data**	**Satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
						(BT) several times daily.
ID: DM N 05	Water Information Research and Development Alliance General information	x	x			knowledge and experience of the collaborating partners
ID: DM N 06	Climate Kelpie					
ID: DM N 07	National Drought Mitigation Center	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 08	National Weather Service	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 09	National Climatic Data Center	x	x			In-situ data, satellite and model data, paleoclimate data and data from NOAA's Regional Climate Centers.
ID: DM N 10	High Plains Regional Climate Center	x	x			Stations used are from the National Weather Service Cooperative Observer Network (COOP), and the Automated Weather Data Network (AWDN).
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	x	x			NRCS collects data via in-situ networks National Weather Service
ID: DM N 12	Bureau of Reclamation	x				Generates data based on in-situ measurements.
ID: DM N 13	Bureau U.S. Army Corps of Engineers	x	x	x	x	In-situ measurements form the input for drought monitoring and alarms
ID: DM N 14	National Aeronautics and Space Administration	x		x		Different satellites provide this information.

ID	Institution	Input				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
ID: DM N 15	Geological Survey			x	x	Hourly in-situ measurements of over 3,000 streamgages
ID: DM N 16	University of Washington	x	x			Inputs are time series of daily or sub-daily meteorological drivers (e.g. precipitation, air temperature, wind speed) Land-atmosphere fluxes, and the water and energy balances at the land surface, are simulated at a daily or sub-daily time step
ID: DM N 17	USFS Wildland Fire Assessment System	x		x		NOAA's AVHRR satellite products for NDVI; and weather station precipitation, latitude, dry bulb temperature for the Keetch-Byram Drought Index
			EUROPE			
ID: DM N 01	European Drought Observatory	x	x	x		Daily moisture data and daily soil moisture anomaly
ID: DM N 02	Drought Management Centre for South-Eastern Europe			x		
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables River flow in representative hydrometric monitoring stations Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x		x		NOAA's AVHRR satellite products for NDVI; and weather station precipitation, latitude, dry bulb temperature for the

ID	Institution	Input				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
						Keetch-Byram Drought Index
ID: DM N 05	System of Prediction and Management of Droughts	x			x	Meteorological conditions (namely reduced precipitation leading to drought situations); Available storage capacities (availability in the main water sources); Consumption requirements for the main water users; Socioeconomic effects associated to drought due to water availability limitations.
ID: DM N 06	The Drought Bulletin	x	x			Monthly cumulated precipitation values
ID: DM N 07	Drought evaluation - Environment Agency	x		x		In-situ data, satellite and model data, paleoclimate data and data from NOAA's Regional Climate Centers.
ID: DM N 08	Integrated project on water and global change	x			x	precipitation and temperature
ID: DM N 09	XEROCHORE	x	x	x	x	Meteorological conditions (namely reduced precipitation leading to drought situations); Available storage capacities (availability in the main water sources); Consumption requirements for the main water users; Socioeconomic effects associated to drought due to water availability limitations.
ID: DM N 10	Drought preparedness network for the Mediterranean	x	x			Collection and analysis of information on drought and drought mitigation Carry out Drought Identification, Risk Analysis, and Best Practices on six

ID	Institution	Input				Remarks
		Monitoring data	Forecast data	Satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
						partner countries Develop guidelines for drought preparedness plans with the participation of institutional and civil stakeholders Verify and test Drought Guidelines on six different partner water basins Disseminate Guidelines as model to Mediterranean countries for formulating their own plans Set up the framework for a Drought Preparedness Network for the Mediterranean countries

8.3.3.2 Zimbabwe

Table 37 shows comparison of available forecasting input data generated in Globally, Europe and Zimbabwe.

Table 36Table 37: Comparison of forecasting input data

Organisations/Institutions being compared	Aspect of comparison	Differences		Similarities
		State of the Art: Europe /US	Africa :Zimbabwe	
SADC drought Monitoring Center/SACORF and Drought Management Centre for South-Eastern Europe (DMCSEE)	**adequacy**			
	Accuracy			Both systems are relatively accurate as they use almost similar input methods (satellite based data)
	Purpose		monitor floods	Monitoring and assessment of drought risks and vulnerability
	Input data	Meteorological data (GPCC data)	Meteorological data	
Meteorological Services Department (Zimbabwe) and Australia Bureau of Meteorology	**adequacy**	good	fair	
	Accuracy	Very good	fair	
	Purpose			Monitoring, Forecasting, warning, response
	Input data	BoM & SILO gridded weather data, US MODIS, ESA AATSR, AVHRR	Meteorological data fusing in both situ and satellite based methods. More bias towards in situ input data	
ZINWA and Water Information Research and Development Alliance	**adequacy**		inadequate	
	Accuracy	accurate	Fairly accurate	
	Purpose		planning, coordination, management of water resources and the delivery of water	Monitoring, forecasting
	Input data	BoM & SILO gridded weather data, US MODIS, ESA AATSR, AVHRR	In situ hydrological data.	
AGRITEX in collaboration with NEWU and FAO and Managing Climate Variability/ Climate Kelpie	**adequacy**	Fairly adequate	Limited input data; unavailability of advanced data input technology	
	Accuracy	accurate	fair	
	Purpose		Assessment of vulnerability status	warning, response
	Input data		Food security data;	

8.3.4 West Africa - Mali

Table 38 shows comparison of available forecasting input data generated in Globally, Europe and Mali. The meteorological data the is available is mainly used as an input data to the models available for drought monitoring, this is found in globally, Europe and also in Africa. Hydrological data is mainly used in European countries as historical data is readily available

Table 38: Comparison of forecasting input data

ID	Institution	Input				Remarks
		Monitoring data	forecast data	satellite data	River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.	
AFRICA						
	Meteo Mali and Meteo France	x	x			Climate variability (wind speed, direction, temperature and insulation)
	AGRHYMET/ PRESAO Nationale Directorate of Hydrology					Water height, time of flood wave propagation from upstream to downstream (Mopti and Koulikoro)
	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	x			x	Early Warning System (SAP)
	The information comes from AGRHYMET and the National Directorate of Hydrology.		x			Prediction System of Information and Early Warning on flood of the Niger Delta (SPIAC)
GLOBAL						
ID: DM N 01	National Australia Bureau of Meteorology	x				Climate variability (wind speed, direction, temperature and insulation)
ID: DM N 02	Commonwealth Scientific and Industrial Research Organisation	x		x		Different satellites provide this information.

ID	Institution	Input				Remarks
		Monitoring data	**forecast data**	**satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
ID: DM N 03	Managing Climate Variability	x				To improve communication between scientists and farmers. Same as Kelpie
ID: DM N 04	Australian Water Availability Project	x			x	Daily fields for rainfall, maximum and minimum temperature, continental observations of brightness temperature (BT) several times daily.
ID: DM N 05	Water Information Research and Development Alliance General information	x	x			knowledge and experience of the collaborating partners
ID: DM N 06	Climate Kelpie					
ID: DM N 07	National Drought Mitigation Center	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 08	National Weather Service	x	x			Temperatures(air, min, max, soil), Precipitations, Atmospheric pressures, Wind direction and speed, Evaporation, Humidity
ID: DM N 09	National Climatic Data Center	x	x			In-situ data, satellite and model data, paleoclimate data and data from NOAA's Regional Climate Centers.
ID: DM N 10	High Plains Regional Climate Center	x	x			Stations used are from the National Weather Service Cooperative Observer Network (COOP), and the Automated Weather Data Network (AWDN).
ID: DM N 11	Department of Agriculture, Natural Resources Conservation Service	x	x			NRCS collects data via in-situ networks National Weather Service

ID	Institution	Input				Remarks
		Monitoring data	**forecast data**	**satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
ID: DM N 12	Bureau of Reclamation	x				Generates data based on in-situ measurements.
ID: DM N 13	Bureau U.S. Army Corps of Engineers	x	x	x	x	In-situ measurements form the input for drought monitoring and alarms
ID: DM N 14	National Aeronautics and Space Administration	x		x		Different satellites provide this information.
ID: DM N 15	Geological Survey			x	x	Hourly in-situ measurements of over 3,000 streamgages
ID: DM N 16	University of Washington	x	x			Inputs are time series of daily or sub-daily meteorological drivers (e.g. precipitation, air temperature, wind speed) Land-atmosphere fluxes, and the water and energy balances at the land surface, are simulated at a daily or sub-daily time step
ID: DM N 17	USFS Wildland Fire Assessment System	x		x		NOAA's AVHRR satellite products for NDVI; and weather station precipitation, latitude, dry bulb temperature for the Keetch-Byram Drought Index
EUROPE						
ID: DM N 01	European Drought Observatory	x	x	x		Daily moisture data and daily soil moisture anomaly
ID: DM N 02	Drought Management Centre for South-Eastern Europe			x		
ID: DM N 03	Hydrological drought evaluation system	x			x	Volumes stored in reservoirs Groundwater tables

ID	Institution	Input				Remarks
		Monitoring data	**forecast data**	**satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
						River flow in representative hydrometric monitoring stations Reservoirs discharges Precipitation in representative monitoring stations Water stored in the form of ice and permafrost
ID: DM N 04	Drought Observatory	x		x		NOAA's AVHRR satellite products for NDVI; and weather station precipitation, latitude, dry bulb temperature for the Keetch-Byram Drought Index
ID: DM N 05	System of Prediction and Management of Droughts	x			x	Meteorological conditions (namely reduced precipitation leading to drought situations); Available storage capacities (availability in the main water sources); Consumption requirements for the main water users; Socioeconomic effects associated to drought due to water availability limitations.
ID: DM N 06	The Drought Bulletin	x	x			Monthly cumulated precipitation values
ID: DM N 07	Drought evaluation - Environment Agency	x		x		In-situ data, satellite and model data, paleoclimate data and data from NOAA's Regional Climate Centers.
ID: DM N 08	Integrated project on water and global change	x			x	precipitation and temperature
ID: DM N 09	XEROCHORE	x	x	x	x	Meteorological conditions (namely reduced precipitation leading to drought situations); Available storage capacities (availability in the main water sources);

ID	Institution	Input				Remarks
		Monitoring data	**forecast data**	**satellite data**	**River flows, groundwater levels, water volumes in storage, water quality in rivers and aquifers, water use and restrictions, water entitlements and water trades.**	
						Consumption requirements for the main water users; Socioeconomic effects associated to drought due to water availability limitations.
ID: DM N 10	Drought preparedness network for the Mediterranean	x	x			Collection and analysis of information on drought and drought mitigation Carry out Drought Identification, Risk Analysis, and Best Practices on six partner countries Develop guidelines for drought preparedness plans with the participation of institutional and civil stakeholders Verify and test Drought Guidelines on six different partner water basins Disseminate Guidelines as model to Mediterranean countries for formulating their own plans Set up the framework for a Drought Preparedness Network for the Mediterranean countries

8.4 COMPARATIVE ANALYSIS OF FRAMEWORK CONDITIONS - RESOURCING

This section highlights the main similarities and differences how the systems are resourced

8.4.1 Equatorial Lakes Region

8.4.1.1 Rwanda and Burundi

Drought monitoring and forecasting in Rwanda and Burundi have a number of limitations in terms of resources compared to the state-of-the-art practices. While other countries (like USA and Australia) have highly skilled staff and high quality equipment, in Rwanda and in Burundi, Infrastructure is still poor (equipment, software, monitoring station network not covering all areas, no weather RADAR station, and no upper air station, etc.). In addition, there is a gap of enough skilled technicians and professionals to handle weather and climate information. Even financial resources are limited though efforts are being made. For example, in Rwanda, nowadays, effort is being made to strengthen RMS in order to bring it to the improved level. In this perspective, two projects are operating under Rwanda Environmental Management Authority (REMA). These projects are "**Supporting Integrated and Comprehensive Approaches to Climate Change Adaptation in Africa"** known as AAP "Africa Adaptation Programme" supported by the Government of Japan and the other one is about **Reducing Vulnerability to Climate Change by Establishing Early Warning and Disaster Preparedness Systems and Support for Integrated Watershed Management in Flood Prone Areas'** supported by the Least Developed Countries Adaptation Fund under the Global Environment Facility known as LDCF. These project are under progress and, among other activities, the following are part of actions: Automatic Weather Stations (30), rain-gauges (50); Automatic weather kits for school (30), 2 computers for modeling and operational forecasting for availing early warning information with associated software, Computers for practical training course to be conducted in Rwanda, Hydro-met stations (10 to be installed and 2 mobile), training of young technicians, etc. These activities will cost around 1,500,000USD [Source: Rwanda Environmental Management Authority].

8.4.2 Eastern Nile Region (Downstream countries)

8.4.2.1 Comparative analysis - Egypt

Table 39 compares resources for early warning systems in Egypt to "state of the art".

Table 39: Forecasting Systems in Regional and other systems relevant to Africa (Resource)

System_ID	Resource	Similarities	Differences	System Level
DM-R01 to DM-R08	International experts, financial support, technology transfer	Building capacity for technical staff, developing forecasting systems	Level of application	*Regional system*
DM-AC01 to DM-AC03	Financial supports, technical resources, international experiences	Developing early warning system for climate change	Infrastructure, level, different level of mitigation and adaptation measures	*Africa Continental*
DM-NNA01 to DM-NNA13	Financial supports, technical resources, international experiences	Developing a real time system	Purpose of the system Spatial resolution, level of technology required	*Northern Africa*
DM-NEA03, DM-NEA04, DM-, NEA06	Financial supports, technical resources, international experiences	National level of application, concerning sectors	Different level technical support required, infrastructure	*Eastern Africa*
DM-NSA01, DM-NSA03	Financial supports, technical resources, international experiences	Developing forecasting system		*Southern Africa*
DM-NWA02, DM-NWA03, DM-NWA04	infrastructure, international experts	Developing forecasting system	Different Level of well trained persons, national financial support	*Western Africa*
DM-ENA04	Trensfer high technology,			*Europe and North Africa*

System_ID	Resource	Similarities	Differences	System Level
DM-EAC01 to DM-EAC03				*Europe and Continental Africa*

8.4.2.2 Sudan

The SMA collect data direct from the weather stations in Sudan but also get another data from different resources e.g.

- CCD – TAMSAT, University of Reading, Department of Meteorology
- NDVI- FAO FTP Website.
- Cloud imagery (CCD) from IGAD& ICPAC, WMO
- IGAD Climate Predication and Application Centre (ICPAC)

8.4.3 Southern Africa

8.4.3.1 South Africa

Table 40 compares resources for early warning systems in South Africa to “state of the art”. The following are the main attributes applied in the comparison:

- Research funding programmes
- Collaboration of institutions
- Distribution of centres around the country
- Available workforce
- Available network stations
- Capacity Building
- Systems to disseminate information

There is emphasis into research for monitoring of drought globally and Europe even though there is an improvement in South Africa. Institutions collaborate to combine skills available thus improving the quality of the product. Effort has been made on water resources assessment in Africa and also with hydrological modelling. More effort is to be channeled towards water assessment and data acquisition and compatibility for the use with other models. The centers are distributed through the country for collection of data and dissemination of available information. This information in disseminated through internet, television, radio newspapers and bulletin. More skillful people are needed in Africa for research programmes that are made available and for analysis and interpretation of information.

Table 40: Comparison of available forecasting resources

Action	Global	Europe	South Africa
Funding for research programmes on:			
• Water resources assessment	x		x
• Hydrological modelling	x	x	x
• Water accounting	x		
• Data compatibility	x		
Information and links to other websites	x	x	
Collaboration with other institutions/partners (NASA, NOAA, USGS, WMO,UN etc.) for:	x	x	
• Climate based monitoring	x	x	
• GI Science and analysis (researching ways to use data from satellites and other remote sensing devices to measure drought)	x		
• Planning and social science			
Distribution of centres around the country:			
• Basin Authority		x	
• Headquarters	x	x	
• Regional support centres	x	x	
• River forecast centres		x	
• National centres	x	x	x
• Climate centres		x	
• Workforce/extension officers	x	x	x
Available Skills:			
• Scientists	x	x	x
• Technicians	x	x	x
• Support staff	x	x	
Capacity building	x	x	x
Availability of network stations	x	x	
Dissemination of information (internet, television, newspapers, email, bulletins etc.)	x	x	x

8.4.3.2 Zimbabwe

Table 41 shows a few selected key organisations from Zimbabwe and their sources of funding. Local organisations receive funding mainly from government and they are governmental affiliated institutions; whereas for state o the art they are a few governmental institutes. Moreso the funds for these local institutions are very little and limited and some projects are done in conjunction with Non-governmental organisations (NGOs).

Table 41: Comparison of available forecasting resources

Organization	Source of funds
AGRITEX(NEWU);FAO	Government; UN
Meteorological Services Department of Zimbabwe(MSD)	Government
Zimbabwe National Water Authority(ZINWA)	Government; Donor
SADC DMC	SADC;WMO;UNDP;
SARCOF	SADC

8.4.4 West Africa - Mali

Table 42 shows comparison of available forecasting resources Globally, Europe and Mali in terms of the fooling attributes:

- Research funding programmes
- Collaboration of institutions
- Distribution of centres around the country
- Available workforce
- Available network stations
- Capacity Building
- Systems to disseminate information

Communication and dissemination of information are needed for better decision making at the grassroots level. All populations have no access to national television. Local radio stations broadcast information at the grassroots level. There are other communication mechanisms that also disseminate information, such as the Weekly Magazine of the Regional Directorate of Fisheries. In addition to the above mentioned ways, the interventions of the City Council and Administration at the prefecture level contribute to the dissemination of information in the database

Table 42: Comparison of available forecasting resources

Action	Global	Europe	Mali West Africa)
Funding for research programmes on:			
• Water resources assessment	x		x
• Hydrological modelling	x	x	
• Water accounting	x		
• Data compatibility	x		
Information and links to other websites	x	x	
Collaboration with other institutions/partners (NASA, NOAA,	x	x	

Action	Global	Europe	Mali West Africa)
USGS, WMO,UN etc.) for:			
• Climate based monitoring	x	x	
• GI Science and analysis (researching ways to use data from satellites and other remote sensing devices to measure drought)	x		
• Planning and social science			
Distribution of centres around the country:			
• Basin Authority		x	
• Headquarters	x	x	
• Regional support centres	x	x	
• River forecast centres		x	x
• National centres	x	x	x
• Climate centres		x	
• Workforce/extension officers	x	x	x
Available Skills:			
• Scientists	x	x	
• Technicians	x	x	
• Support staff	x	x	
Capacity building	x	x	
Availability of network stations	x	x	x
Dissemination of information (internet, television, newspapers, email, bulletins etc.)	x	x	x

8.5 GENERAL OBSERVATIONS

8.5.1 Response of users to the warnings or forecasts

8.5.2 Time taken to respond

Different users take varied time to respond either to forecasts or warnings issued .An example is the Drought case of 1992, when the drought warning was issued as early as March 1991, by SADC REWS and the Zimbabwean government only responded as; late as March 1992.As such this stalled resource mobilisation and thus the effects of this drought was significant. It was not until such stocks had dropped to critical levels that reactions were initiated, by which time it was already too late to avoid the maize shortages which hit countries like Zambia and Zimbabwe during the early part of 1992(Pawadyira and Ndlovu 1993) The time taken lag between a warning or forecast and response, can cause a big difference in drought mitigation and adaptation.

8.5.3 Coordination of responses

The GOZ realized the need to develop appropriate action plans to counter both the short-term and long-term effects of drought, to develop institutional capacity, and to invest more resources in order to meet the needs of the most vulnerable population groups. To address these issues, the GOZ developed the National Policy on Drought Management (NPDM), which was formulated in 1998 and approved in 1999 (GOZ-NEPC, 1999). The response by the Government of Zimbabwe (GOZ), local communities and authorities, as well as donors, has focused on short-term emergency response. (FAO, 2004). Most local government authorities lacked the capacity to react to these disasters, let alone prepare for them in an effort to mitigate the possible impact of drought. (FAO, 2004). Due to the hierarchical nature of the coordination team which is led by local government authorities, in most cases responses take time to be implemented.

8.5.4 Utilization of the information

Using the information was more difficult in the smallholder sector, especially among communal land farmers in drier regions of the country, where “below-normal” rainfall implied a high likelihood of crop failure. Most communal land farmers did not change their behaviour in response to the1997/98 forecast, and very few sold their animals. Some farmers, particularly among those in the driest region, waited until December or January (i.e., late) to plant their millet, sorghum, or maize, after having seen early season rainfall turn out to be relatively normal. These farmers fared poorly when the rains ended early, as predicted. Taking this 1997/98 drought case as example, some farmers may not use or take heed of the drought monitoring information; especially communal farmers. These above three key users have different user requirements, as well as type information required .But these groups have the following constraints common

i. Timeliness of the warning or forecasting information

This influences the level of preparedness and ability to mitigate the effects of drought. In terms of being able to provide earlier, and at the same time reliable, crop forecasts, a major breakthrough in the application of climatological information for early warning is required. At present the types of advice issued on such phenomena as ENSO are not sufficiently reliable or dependable to be able to be used in crop harvest forecasts, partly because general global links are frequently overshadowed by localized climatic effects and partly because such advice is not yet sufficiently prognostic.

ii. Accuracy/relevance of information

Information need to be usable and dependable. In this respect, ENSO bulletins need to be more user-oriented (users, in an early warning context, are not always climatologists or meteorologists), providing assessments of the likely impact (e.g., risk analysis) on rainfall and other weather conditions in particular parts of the world. Forecast by Meteorological Services Department (MSD) are relevant only to seasonal timescales and relatively large areas and may not fully account for all factors that influence weather and climate.

iii. Adequacy of information

Zimbabwean forecasting organisations (MSD; ZINWA etc.) rely more on in-situ input data collection methods .The number of stations are limited, leading to inadequate output data or forecasts and as such inadequate information for the users. In most cases the information tends to be more generalised.

iv. Specificity of information

Local area specific forecast are important to users, especially farmers. In Zimbabwe forecasts used in are broad based in terms of area coverage and as such fail to reliably forecast specific localities. Most of these early warning or forecasting products need to be downscaled to give reliable information.

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