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

(DEWFORA)

A 7th Framework Programme Collaborative Research Project

Work Package 5

Enhanced drought early warning for better decision making and preparedness in Africa

DELIVERABLE 5.4 - RECOMMENDATION FOR ENHANCING DROUGHT PREPAREDNESS AT THE LOCAL AND REGIONAL SCALES

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SUMMARY

This report presents some recommendations for enhancing drought preparedness in Africa in a changing climate, being the Eastern Nile and the Niger basins the target case studies.

In this context, the Deliverable 5.4 firstly presents the identification of the best practices in what concerns drought early warning systems and mitigation and adaptation practices, according to the state-of-the-art methodologies followed on drought management experienced countries/regions: Europe, USA and Australia.

Secondly, the reality of the targeted case studies is generally described regarding the main present capabilities in terms of drought monitoring, forecasting and response, as well as the local concerns expressed by stakeholders. All this information was used to support the identification of some recommendations on technical development for drought monitoring, forecasting and response on both case studies.

The final objective, for both case studies, was to propose general improvements envisaging an improved drought monitoring and forecasting and also an adjusted institutional framework, for example through the creation of an institution specifically responsible for drought management.

In both case studies it was verified that climate change should be taken into account for drought prevention and particularly for the definition on adaptation measures, since an increase in climate variability is expected. Thus, some of the recommended improvements can be very important, namely on data quality, data sharing and on better skills (human resources/knowledge and technical resources).

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List of abbreviations

ABFN - *Agence du Bassin du Fleuve Niger* (Niger River Basin Agency)

ACMAD - African Centre of Meteorological Application for Development

ADI - Aggregate Drought Index

AEDD - *Agence de l'Environnement et du Développement Durable* (Agency for Environmental and Sustainable Development)

AMMA - African Monsoon Multidisciplinary Analyses

BLI - Base flow indices

CCAM - Conformal-Cubic Atmospheric Model

CILSS - *Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel*

CMI - Crop Moisture Index

CRA - *Centre Regional Agrhymet*

CSA - *Commissariat à la Sécurité Alimentaire* (Food Security Committee)

CSIR - Council for Scientific and Industrial Research

CSIRO - Commonwealth Scientific and Industrial Research Organisation

DAI - Discharge Anomaly Index

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

DEWS - Drought Early Warning Systems

DNH - *Direction Nationale de l'Hydraulique* (National hydraulic agency)

DNM - *Direction Nationale de la Météorologie* (National Meteorological Agency)

DPPC - Disaster Prevention and Preparedness Committee

DRMFSS - Disaster Risk Management and Food Security Sector

ECHO - European Community Humanitarian Office

ECMWF - European Centre for Medium-Range Weather Forecasts

EMA - Egyptian Meteorological Authority

ETDI - Evapotranspiration Deficit Index

EU – European Union

EWS - Early Warning System

EWX - Early Warning Explorer

FEWS NET - Famine Early Warning Systems Network GMI - Generalized Monsoon Index

FSCD - Food Security Coordination Directorate

GDP - Gross Domestic Product

HADA - High Aswan Dam Authority

HIC - Humanitarian Information Centre

IND - Inner Niger Delta

INRM - Integrated Natural Resource Management

IRBM - Integrated River Basin Management

IRI – International Research Institute for Climate and Society

IUCN - International Union for Conservation of Nature

IWRM - Integrated Water Resources Management

MWRI - Ministry of Water Resources and Irrigation

MOARD - Ministry of Agriculture and Rural Development

NBA - Niger Basin Authority

NDVI - Normalized Difference Vegetation Index

NFC - Nile Forecasting Centre

NFS - Nile Forecast System

NGO - Non-Governmental Organization

NMDI - Normalized Multi-Band Drought Index

NMHS - National Meteorological and Hydrological Service

NMSA - National Meteorological Services Agency

NRMD - Natural Resource Management Directorate

NWP - Numerical Weather Prediction

NWS - Nile Water Sector

OCHA - Office for the Coordination of Humanitarian Affairs

OPIDIN - *l´Outil de Prédiction de l´inondation dans le Delta Intérieur du Niger*

OSS - *Observatoire du Sahel et du Sahara*

PET - Potential Evapotranspiration

PRMC - *Programme de Restructuration du Marché Céréalier* PDSI - Palmer Drought Severity Index

PSNP - Productive Safety Net Program

RAI - Rainfall Anomaly Index

RDI - Reconnaissance Drought Index

REDDIN - *Rehabilitation des Ecosystemes Degrades du Delta Interieur du Niger*

RI - Recession Indices

ROSELT - *Réseau d'Observatoires de Surveillance Écologique à Long Terme*

SAP - *Système d'Alerte Précoce*

SDAP - Sustainable Development Action Plan

SDI - Standardized Discharge Index

SFI - Standardized Flood Index

SIEREM – *Système d'Informations Environnementales sur les Ressources en Eau et leur Modélisation*

SIP - *Système Informatique de Prévision*

SMA - Sudan Meteorological Authority

SPI - Standardized Precipitation Index

SPIAC - *Système de Prédiction, d´Information et d´Alerte sur les Crues*

SRI - Standardized Runoff Index

SWAC - Sahel and West Africa Club

SWI - Standardized Water Level Index

SWSI - Surface Water Supply Index

USA – United States of America

VegDRI - Vegetation Drought Response Index

WASCAL – West African Science Service Centre on Climate Change and Adapted Land Use

WFP - United Nations World Food Programme

WP – Work Package

YMI - Yield Moisture Index

1. Introduction

The main objective of this deliverable is to present recommendations for enhancing drought preparedness at the local, national and trans-boundary basin scales and for coping with drought under a changing climate. This report is integrated in Task 5.3 – Preparedness and adaptation to drought in a changing climate, which objectives are: (i) to assess, in selected case studies: case study 6.1 (Eastern Nile) and case study 6.4 (Niger), whether and how climate change impacts on the effectiveness of the supportive framework for drought early warning and (ii) to recommend adaptation measures reassuring framework's effectiveness, and taking into account the climate and policy context.

To do so, first of all, the best identified practices on the subject are presented, aiming that these may be adapted to regional and local concerns in each case study. These best practices regard the development and use of drought early warning systems (that include the monitoring, forecasting and response components) and suggestions on drought mitigation and adaptation practices. These identified best practices/methods were based on the European, USA and Australian experiences, regarding the information compiled on WP2.

Secondly, an evaluation of Case Studies drought preparedness capabilities and concerns is made. For this, it is performed an identification of what are: (i) the societal capacities, both in terms of drought monitoring and forecasting, and also in terms of drought mitigation and adaptation practices; (ii) the climate risks that could increase case studies vulnerability to future drought hazards and (iii) the local concerns of stakeholders. It should be referred, however, the lack of information available that limited (i) the characterization of the reality of each case study, and (ii) the inter-comparison of both case studies.

Finally, some recommendations to improve drought preparedness in Eastern Nile and Niger Case Studies are presented, according to the science available, the identified climate risks and also to case studies' characteristics. Obviously, due to the above referred lack of information, the recommendations presented are mainly general, and the possibility of extrapolation for the other countries of Africa is quite reduced.

The structure followed for this deliverable is presented in Figure 1.

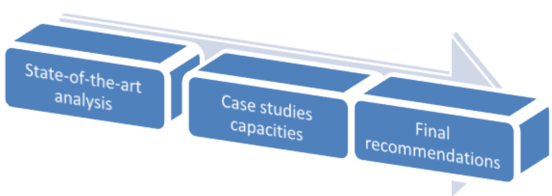


Figure 1. Structure followed for D5.4.

2. Selection of best practice strategies that can be adapted to regional and local concerns in case studies

In what concerns early warning systems and drought mitigation and adaptation measures, the available science is an important tool to improve drought preparedness in Africa. The best methods and practices identified based on European, USA and Australian knowledge and experience could be adapted to regional and local concerns in Eastern Nile and Niger case studies in order to improve the preparedness to drought response.

According to the available information, several countries in EU, and states in USA, are already monitoring drought continuously and applying regional and/or national drought management plans. Also, various activities are being implemented, that contribute to drought preparedness' improvement such as: drought observation and forecasting indicators based on information collection and dissemination, impact and risk assessments, development of mitigation and adaptation measures, development of a drought policy framework, etc. Moreover, in the specific case of Australia there is a national drought policy based on principles of sustainable development, risk management, productivity growth and structural adjustment mainly focused in the agricultural sector.

In all cases, it is possible to conclude that a good framework for cooperation, clear definition of roles and efficient integration and use of information is vital. In the following topics some examples of the main state-of-art practices in what regards Drought Early Warning Systems (DEWS) and Drought Mitigation and Adaptation techniques are further described, aiming that these could be applied in the referred case studies.

2.1. Drought Early Warning Systems (DEWS)

The science available for Drought Early Warning may be described following 3 main topics: (i) the necessary input data, (ii) the characteristics of ideal drought early warning systems and (iii) the main institutions that should be involved in drought monitoring and forecasting. These three topics are essential for drought management, since data collection is the first step of the process, allowing the conception of monitoring and forecasting products, and providing support for decision making and preparation/response to drought situations. On the other hand, the main features of the drought early warning system, will depend on science available, but also on regional specificities, as for example the importance of the agricultural sector, or the dependence on the existence of flooding events, etc. Finally, the understanding of the national institutional regime is a key factor for establishing effective and integrated drought management plans that incorporate monitoring, forecasting, public participation, and contingency plans.

a) Necessary input data

In order to define the components of a drought monitoring and forecasting system it is important to define what needs to be monitored and forecast. First of all, drought is a condition that originates from a deficit of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector, and so drought is closely related to the hydrological cycle.

Moreover, droughts can, mainly, be classified in four types, for management and operational purposes: meteorological, agricultural, hydrological, and socio-economic. Meteorological drought refers only to the deficiencies of precipitation from normal that is beyond all types of droughts; agricultural drought occurs when the precipitation shortages results in deficit of soil moisture and therefore, a water deficit in vegetation produces agricultural impacts; in the hydrological drought there is a shortfall on surface or subsurface water supply due to the large periods of precipitation deficit; finally, socioeconomic droughts occurs when the demand for an economic good, such as water, forage, food grains, fish, and hydroelectric power, exceeds supply as a result of a weather-related shortfall in water supply and represents a severe impact for economy and society.

For drought monitoring and forecasting, it is required to monitor and model the different components of the hydrological cycle, including the storage of water in the ground, soils, rivers, lakes or surface reservoirs, as well as the transfer of water through these different components, in the form of precipitation, evapotranspiration, runoff, etc. Some other parameters may also contribute to the study of drought conditions. Wind and irradiation might affect the spatial distribution of rain and other processes, again affecting the hydrologic cycle and therefore influencing drought impacts. Vegetation can also store water, but more importantly, it is a proxy[1] to know more about the soil water conditions. Observing vegetation might give indications of potential drought in agricultural contexts.

The most commonly parameters used for drought monitoring and forecasting are listed in Table 1, according to the type of drought.

[1] A proxy is an indicator or an indirect measure for something else.

Table 1. Parameters to monitor and forecast drought according to its type.

Drought Type	Parameters to monitor and forecast
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; people interactions, health and quality of life. Population numbers, household income, economic indicators such as GDP.

The detection of droughts is difficult because not every period where the parameters (e.g. precipitation) are below normal values will result in a drought event. The drought history and the duration of the deficit are of major importance too. A complex methodology is required for definition of threshold values for each of the parameters mentioned above, reflecting the existence of drought impacts and so a record of impacts during drought events will be as necessary for drought preparedness improvement as the meteorological or hydrological time series.

b) **Drought Early Warning Systems (DEWS) –** "state-of-the-art" monitoring and forecasting features

The Drought Early Warning Systems are grounded on monitoring and forecasting systems. The four main goals of a DEWS application are: (i) monitoring and forecasting of drought parameters, (ii) data processing, (iii) data management and (iv) making information available to the public.

Analysing the available state-of-the-art systems, the main relevant identified features are:

- Collection of information using in-situ or satellite technology (stream gauges and weather stations are examples of in-situ technologies; satellite technology is useful, for example, for monitoring vegetation).
- Use of a web-based information system:
    - the flow of data from observation networks to databases is often automated;
    - institutions can use standards, systems and programming languages to access data and store it in their own online or offline databases;
    - their models can access it and make runs for forecasting or for data post-processing for informative visualization.

- Data is processed using models and GIS tools. For monitoring, the indices are calculated with observed data. For forecasting, models are used to produce the data needed for indices calculation (based on possible future scenarios):
  - e.g. of models: VIC or NLDAS;
  - e.g. of GIS tools: GrADS and ESRI ArcGIS.

  Monitoring and forecasting products are often produced for several time intervals. The smallest and most recent interval is real-time information, but this is not always possible or relevant. Meteorological or hydrological data is often provided in near-real time or at daily intervals. The smallest time-interval for the delivery of drought information is often the week. Monitoring information will often provide averages for the past week, 2 weeks, month, season, half year, year, or 2 or 3 years. Forecasting efforts will often use the same time-frames to look into the future.

- Definition of drought risk maps with a simple classification of droughts risk (normal, moderate, high) for geographically and environmentally defined regions or catchments.

- Estimation of socio-economic and environmental impacts associated to the potential water deficits (e.g. reduction of crop yields) and management of water demand and supply for the key sectors: agriculture, energy production, residential water use, water-intensive manufacturing.

- Recommendations to farmers, water companies and other users, describing the actions to adopt to withstand the potential impacts drought.
- To provide the necessary support for decision makers and to enable a continuous assessment of the need for improvement of the monitoring infrastructure.

Figure 2 presents a schematic representation of data processing in drought early warning systems, mentioning which are the main inputs and outputs of these processes.

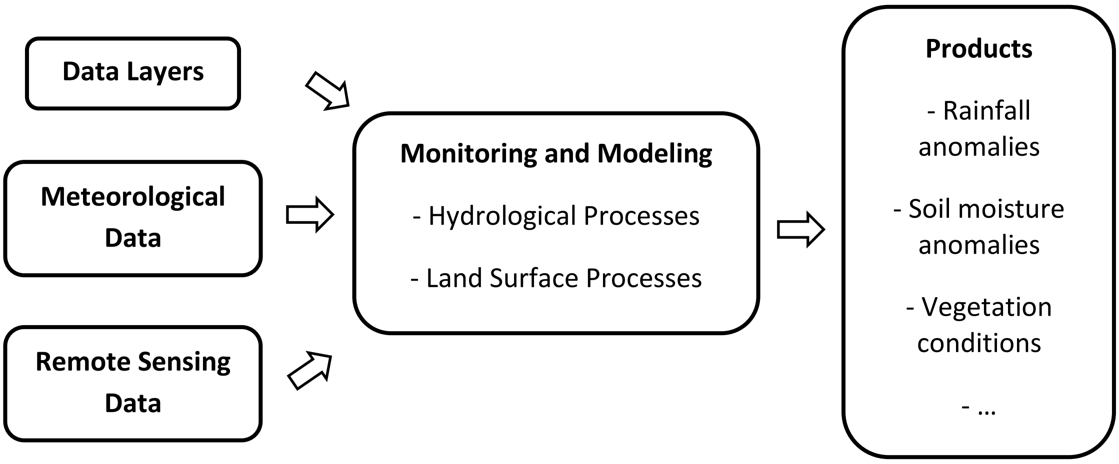


Figure 2. Schematic representation of data processing.

Some of the common indices calculated with the parameters monitored are:

- Standardized Precipitation Index (SPI);
- Palmer Drought Severity Index (PDSI);
- Keetch-Byram Drought Index;
- Surface Water Supply Index (SWSI);
- Crop Moisture Index (CMI);
- Normalized Difference Vegetation Index (NDVI) (Remote Sensing-based product);
- Water deficits;
- Vegetation health indicators (Reduction of crop yields);
- Etc.

c) Institutions to be involved

Effective drought preparedness requires coordinated actions and, so, an effort of coordination among the affected stakeholders is also required. According to the state-of-the-art practices there are four types of institutions that should be involved:

- Level 1: Institutions that operate in-situ monitoring networks or satellites

Some institutions are involved in monitoring meteorological or hydrological conditions in the areas or river basins they are responsible for, without necessarily providing forecasting information. Often, these institutions closely monitor in-situ hydrologic and climatic conditions. They may store this information in their own databases and provide it, together with outlooks, as a service.

– Level 2: Institutions that process data and provide information to the public.

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 data processing, calculating indices for drought monitoring, forecasting or both. To do this in real-time, an architecture allowing an automated process of data is necessary, often combined with a database to store the input data and the results of the forecasting runs. Often an online viewer is part of this architecture allowing disclosure of both the original information and results to the public and to policy-makers.

– Level 3: Institutions that develop monitoring and forecasting methods and tools

Research institutions like universities and institutes like Commonwealth Scientific and Industrial Research Organisation (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.

– Level 4: Institutions responsible for resources management, public services or Earth Observations

The collected data should be shared with institutions with higher hierarchy level in the drought management process. For example in Australia, all institutions that either use or manage water resources are required by law to provide water information to the Bureau of Meteorology.

2.2. Drought mitigation and adaptation practices

Regarding drought mitigation and adaptation it is important to clarify that, drought mitigation is the reduction of the effects of drought impacts that effectively occurred, through economic compensation or implementation of emergency measures to ensure a minimum level of water supply, for example. Drought adaptation is a process of being able to avoid or to overcome potential problems in a drought condition. It refers to changes in processes, practices, and structures to moderate potential impacts of future droughts.

a) Mitigation measures

Drought mitigation practices presented in Table 2 consider short term actions applied to minimize drought effects, according to the correspondent drought alert/ severity level. The general measures, classified as transversal measures, correspond to situations when more than one specific water use sector is involved.

Table 2. Compilation of best practices of drought mitigation measures implemented in Europe, USA and Australia, according to the water use sector and drought severity level of impacts (adapted from Deliverables D2.2 and D2.5).

Drought level	Sector	Description
Normal situation	Transversal measures	Continuous drought monitoring and drought forecasting studies.
		Monitor and forecast future water demand and needs.
		Analysis of available resources and possible optimization of water uses (wastewater reuse, management of surface and groundwater); study the aquifer yield potential and use this information when permitting new uses.
		Definition of strategic water reserves for priority uses (household supply, environmental needs).
		Secure water rights.
		Promote water conservation and drought education, including demonstration projects.
		Maintain old wells and pumping facilities for emergency backup.
Pre-Alert situation	Transversal measures	Realization of public awareness campaigns.
		Analysis of existing infrastructures (abstractions, small reservoirs, etc.) capable of being used in case of drought situation.
		Intensification of pollution discharges control.
		Intensification of environmental flows control.
		Constitution of the technical drought committee to follow up drought evolution.
		Control of drought measures' implementation.
		Monitor water use, register water rights permits, help with contingency and conservation plans for users and utilities.
		Constitution of a "Drought Management Committee".
	Agriculture	Water conservation recommendations for farmers.
		Education of agricultural producers, irrigators, youth, urban dwellers.
		Inventory stock water sources and monitor yields.
		Control of water allocation in irrigation areas.
		Implement soil moisture monitoring program.
		Develop stronger rural communities – the aim is to build community resilience and assist communities to manage significant hardship caused by agricultural downturns.
	Industrial	Reuse of treated effluent.
	Urban water supply	Activation of emergency plans in water supply systems.
Alert situation	Transversal measures	Voluntary use restrictions.
		Use of non-conventional resources (wastewater reuse, water transfers, etc.).
		Adaptation of reservoir exploitation rules.
		Reinforcement of water treatment.
		Increase of water quantity and quality monitoring.

Drought level	Sector	Description
		Reinforcement of water discharges control and increase of penalties for irregular discharges.
		Communication and information on water use and water rights through databases, websites, outreach and a drought reference manual.
	Agriculture	Water use restrictions in irrigation areas.
		Creation of programs that provide financial assistance and social support networks to meet the mental health and other needs of producers who suffer grazing losses due to exceptional droughts.
		Assist in installation of new water distribution facilities.
	Urban water supply	Activation of water systems interconnections.
		Reduction of pressure head during night periods.
		Verification of emergency plan activation for urban supply.
Emergency situation	Transversal measures	Weekly report of drought evolution.
		Intensification of non-conventional resources use for green areas irrigation.
		Intensification of water resources transfer within the river basin.
		Reallocation of water resources.
		Obligatory water use restrictions.
		Restriction in flows to satisfy environmental needs, untill the minimum values defined for the area.
		Intensification of water quality control in reservoirs in risk of eutrophication, avoiding the use of the minimum stored volumes.
		Intensification of pollution discharges control.
		Apply Water Conservation Measures which are mandatory and enforceable; Increase of penalties for irregular discharges, within legal limits, and for anyone found in breach of the restrictions.
	Agriculture	Restrictions of some crops cultivation.
		Control of water use restrictions in irrigation areas.
	Urban water supply	Restriction of water use for certain purposes (car wash, streets washing, private gardens, public parks and gardens and public open spaces: use of hand-held hose with trigger nozzle or bucket, time restrictions on sprinkler and irrigation systems, etc.).
		Use of the minimum or strategic water reserves to cover environmental needs and household supply.
		Water tanks supply.
		Temporary change of water tariffs for urban supply.
		Intensification of water treatment processes to compensate water quality decrease.

b) Adaptation measures

The identification of drought adaptation measures, presented in Table 3, was based on their period of influence (long term) and on the effect on drought vulnerability of a certain region/ water use sector (increasing sustainability of water use and reducing the potential effect/ impact of a drought situation). The short description of the main drought adaptation measures is aggregated by water use sector, and types of measures (scope). Again, the transversal measures are referred to those with wider application and influence than just one specific water use sector.

Table 3. Compilation of best practices on drought adaptation measures implemented in Europe, USA and Australia, according to the water use sector and type of measures (adapted from Deliverables D2.2 and D2.5).

Sector	Type of measures	Description
Transversal measures	Legislation and regulations	Regulations to improve water savings.
	Information and education	Public awareness campaigns (increase awareness about value of water and the importance of water savings), developing publications and educational materials.
	Water recycling and use of nonconventional water sources	Wastewater reuse for specific purpose, reinforcing the use of rainfall harvesting, water cisterns, fog collection, etc.
	Groundwater use and recharge	Groundwater recharge.
		Application of optimization, risk, and decision models.
	Impact management	Contingency planning and definition of emergency actions and plans for drought impacts mitigation.
		Development of an early warning system.
		Application of optimization tools for water allocation and to schedule deliveries.
		Participate in research to advance technology demonstration projects.
	Information systems	Remote sensing, GIS and models that provide the balance between water availability (water storage) and the estimated water demand for different uses.
		Hydrological forecasting and drought monitoring systems.
Agriculture	Demand/Supply management	Selection of crop varieties according to their tolerance to the water stress conditions and their water use efficiency.
		Change sowing dates, plant two crops instead of one, fall crop with a short fallow period.
		Tillage and land-forming practices (soil management).
		Provide loans for individual farmers to install more efficient irrigation equipment.
		Improve surface irrigation measures (use of sprinkler and micro-irrigation systems).
		Adopt water prices that induce farmers to save water and to irrigate during night.
		Governmental help to farmers to manage climate risk on-farm, providing practical tools to incorporate weather and climate information into farm business decisions. To manage the increasing variability, farmers need to adapt their practices.
		Promote research and development: - developing drought tolerant plants and new cropping practices; geographic shift of current varieties; near real time estimation of pasture biomass using daily satellite information.
		Terracing (maximization of soil infiltration).
		Rainwater harvesting with small dams (farm ponds), also to increase aquifer recharge.
	Insurance development	Based on the probability of a reduction in crop yield below a pre-established threshold.
Industrial	Water management	Assist water utilities with development of required municipal

Sector	Type of measures	Description
		water conservation plans and water loss audits; collect data for the required plans and audits.
		Provide resources for industrial, commercial, institutional water conservation programs.
Urban water supply	Water saving practices and management	Municipal water supply and drainage systems - decision-making about sources, prices, water use restrictions (establish rate policies that emphasize greater user involvement in water conservation and saving).
		Actions to improve customers' water efficiency through education and demand management programmes.
		Create new alternative water sources such as rainwater harvesting (water reuse), aquifers and rainwater tanks that can be used as substitutes for potable water when drinking water quality is not essential.
	Water conservation, systems maintenance and management	Adopt low-pressure pipe distribution (to reduce spills and leaks, to achieve higher flexibility and service performance, and to easily adopt water metering).
		Intermediate storage, to increase the flexibility of the system to respond to variations in demand, and also to reduce operation losses during periods of reduced water use.
		Information systems, to identify the state variables of the system, inclusive in real time.
		Construction of new wells or reservoirs, establishing new pipelines.

3. Evaluation of Case Studies capabilities and concerns

The main objective of the present chapter is to assess the current situation of Eastern Nile and Niger case studies, regarding drought management and response, to support recommendations for improvement on following chapter 4. Thus, for each case study were identified the main capabilities in terms of drought monitoring, forecasting and response; the usual drought mitigation and adaptation practices; the risks that could increase the future drought hazards and the local concerns of stakeholders.

The topics of this deliverable were based on information provided by Case Study partners and on several report already available, namely: Deliverable 2.2 – Inventory of institutional frameworks and drought mitigation and adaptation practices in Africa, Deliverable 2.4 – Gap analysis report on drought monitoring and forecasting systems in Africa, Deliverable D 2.5 - Gap analysis report on drought mitigation and adaptation practices and organizational structures for drought management in Africa, Deliverable 6.1 – Implementation of improved methodologies in comparative case studies and also the report of Task 6.6, correspondent to the compilation of responses to the Questionnaire for Performance Assessment on Droughts Evaluation, namely on the existing processes of drought monitoring, forecasting and response in DEWFORA's case studies.

3.1. Case Study 6.1 – Eastern Nile

3.1.1. General characteristics

The Nile River is the longest river in the world (6 550 km); its basin covers 3 400 000 km^2 and encompasses eleven countries in east and central Africa (**Error! Reference source not found.**): Tanzania, Rwanda, Burundi, Congo, Kenya, Uganda, Eritrea, Ethiopia, South Sudan, Sudan and Egypt. From the socio-economic and political points of view, the Nile Basin can be regarded as one of the most important basins in Africa. Water management in the basin has historically been a controversial issue and cause of tensions between the countries, which often have a sole dependency on the Nile as a water resource. Nonetheless, the area of the Eastern Nile case study corresponds to the drainage basins of two Nile river's tributaries, the Blue Nile river and the Atbara river, which encompasses (together) three countries of the Nile basin: Ethiopia, Sudan, and Egypt.

Figure 3 identifies the overall Nile basin map and, within the circle, the Eastern Nile region. The Eastern Nile Region covers a large portion of the Nile Basin and encompasses the sub-basin of

Blue Nile in the middle, and the sub-basin of Atbara in the north. On the other hand Figure 4 is more specific and presents the Atbara and Blue Nile basins.

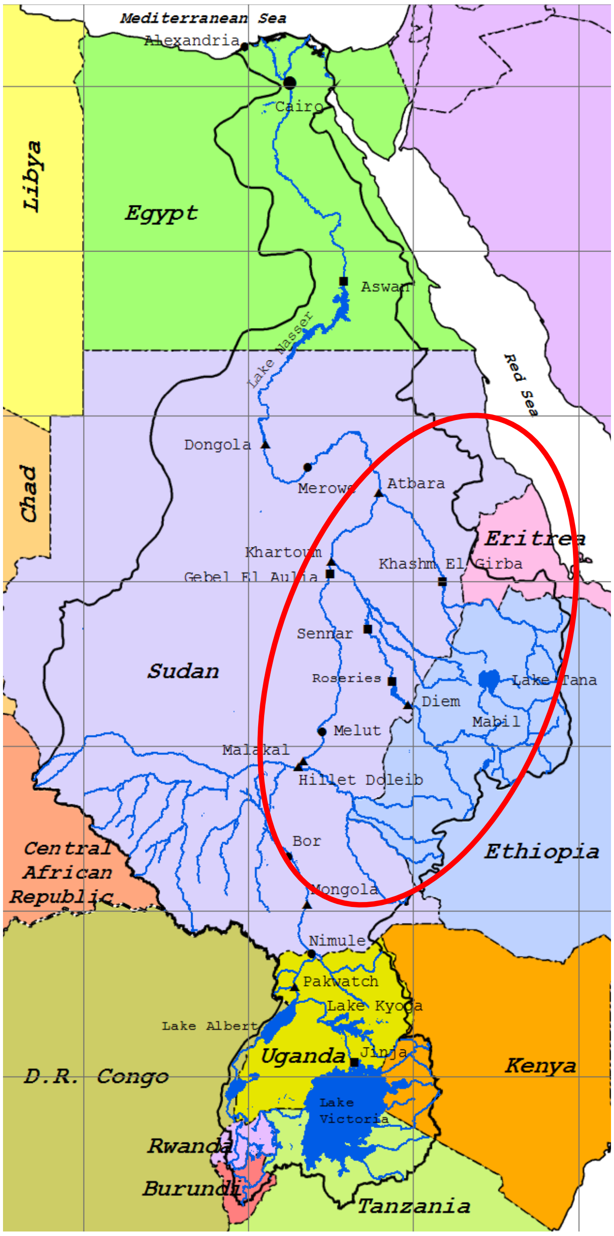


Figure 3. Nile basin map and in the circle the Eastern Nile region.

Source: Deliverable D6.2

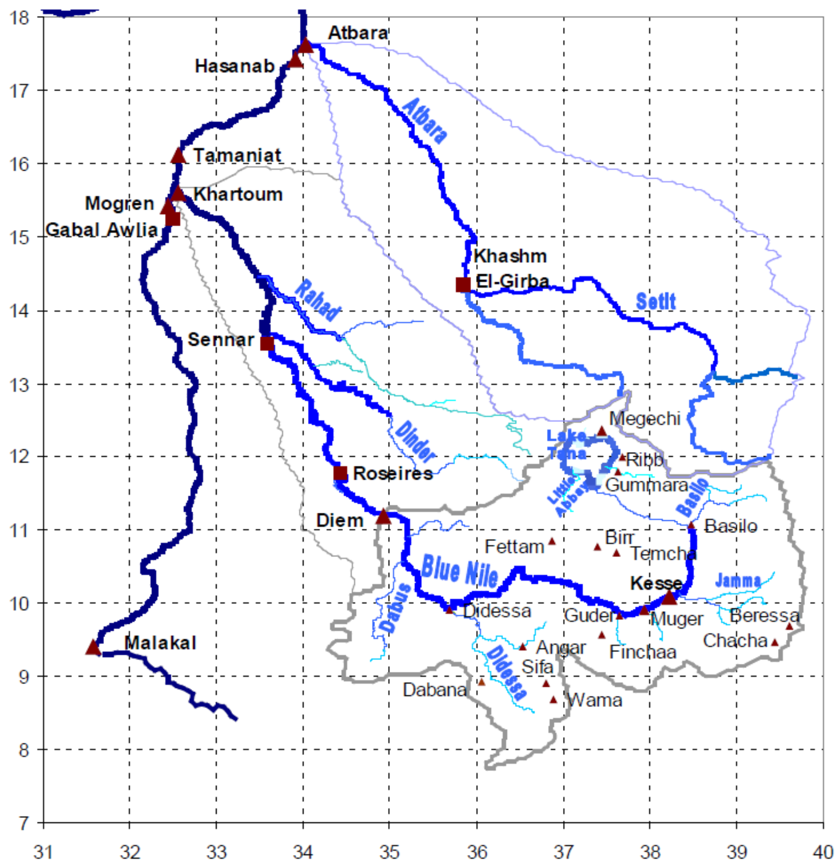


Figure 4. Map of the Blue Nile and Atbara Basins.

Source: Deliverable D6.2

The Blue Nile is a river originating at Lake Tana in Ethiopia. The river is one of the two major tributaries of the Nile. The Blue Nile has a total length of 1 450 kilometres, of which 800 km are inside Ethiopia and the rest is inside Sudan. The Blue Nile flows generally from south from Lake Tana and then west across Ethiopia and northwest into Sudan. Ninety percent of the water and ninety-six percent of the transported sediment carried by the Nile originates in Ethiopia, with 59% of the water from the Blue Nile (the rest being from the Tekezé, Atbara, Sobat, and small tributaries). The Blue Nile basin covers 325000 km^2.

The River Atbara is the last tributary of the Nile river, before the estuary. It originates in the Ethiopian Highlands at north of Lake Tana. However, there is no consensus regarding the drainage area of the Atbara basin. Hurst (1950) reports an area of 100,000 km^2 which is taken forward by Shahin (1985) and Sutcliffe and Parks (1999), while Conway and Hulme (1993) reported a larger area of about 137,000 km^2. The River Setit (called Tekeze in Ethiopia), the major tributary to Atbara, has a catchment area of 68,000 km^2 (Hurst, 1950). Atbara River is 805 km in length.

3.1.2. Institutional Framework

Since there is no drought authority at the Nile basin level and, according to the information collected, the drought management process is done at each country's level, it is more appropriate, in the context of the Eastern Nile region, and specifically, regarding the Blue Nile and Atbara basins, to describe the organizations existing in Ethiopia, Sudan and Egypt . Some of these organizations focus specifically on drought monitoring and early warning (mainly regarding food security) while others aim to provide support for drought mitigation in the affected regions. Thus, the main existing organizations and their corresponding mandates will be explained stressing the drought-related activities for each.

a) Ethiopia

The Ministry of Agriculture and Rural Development (MOARD)

In Ethiopia, the MOARD is responsible for the management of the Productive Safety Net Program (PSNP), with the Disaster Risk Management and Food Security Sector (DRMFSS) responsible for overall program coordination. Within the DRMFSS, the Food Security Coordination Directorate (FSCD), previously called the Food Security Coordination Bureau, facilitates the day-to-day management and coordination of the PSNP. It is directly responsible for the timely delivery of transfers to beneficiaries and supports the implementation of public works.

Through the PSNP in Ethiopia, the Natural Resource Management Directorate (NRMD) is responsible for coordination and oversight of the public works. This includes capacity building and technical support, supervision of environmental guidelines, liaising with FSCD and other PSNP partner institutions on coordination and management of public works, and participation in PSNP design and management forums, including policy issues and the roll out of the pastoral PSNP.

National Meteorological Services Agency (NMSA)

The National Meteorological Services Agency is responsible for the control and operations of short-medium-and long-range forecasts and early warnings. The NMSA develops ways and means for adopting new systems, better techniques and simplified procedures so as to render an efficient and effective weather forecast services.

Contingency Planning and Financing Committee of the Somali Region

Contingency Planning and Financing Committee, also known as Disaster Prevention and Preparedness Committee (DPPC), it is currently mandated with contingency planning that involves food and non-food sectors, consider the effects of food crises like increased incidence of diseases, and that would consider mitigation and recovery interventions to ensure that the continued development of a more robust emergency response system is in process.

The DPPC has a lot of activities related to human health protection and quality; some of these activities are as follows: migration and population tracking, emergency education, special protection needs of women and children and shelter and logistics requirements. One of the main components of the DPPC in Ethiopia is an Early Warning System (EWS) which has been in place since 1976 to monitor and warn against the threat of disasters ahead of time, and to trigger timely, appropriate, and preventative measures. It monitors closely factors which affect food security at household, regional and national levels. The system is an inter-agency activity involving different relevant government institutions. It is led at the national level by a committee with the DPPC acting as its secretariat. Since 1993, The EWS has been decentralized in line with the regionalization policy and bottom-up planning approach.

b) Sudan

Sudan Meteorological Authority

The Sudan Meteorological Authority (SMA) is a governmental body working on monitoring, forecasting of weather parameters and it is considered as an advisor for policy makers in all issues about climate and weather. The SMA also provides data and information for the public and for scientific researches and also work as consultants for some organizations and companies.

c) Egypt

Drought forecasting and management in Egypt focus on hydrological drought and is mainly taken care of the Ministry of Water Resources and Irrigation (MWRI).

Nile Forecasting Centre

The general aim of the centre is to provide tools and information for water planning and management. To this end, the Nile Forecast Centre through various tools including the Nile Forecast System (NFS) will provide to planners and decision-makers in Egypt with:

- Timely forecasts of the Nile River inflows into the High Aswan Dam reservoir;
- Real-time information about hydrological and meteorological processes occurring in the whole Nile Basin; and
- Assessment of climate change and future development impacts on the flow regime of the Nile.

The information available from the NFC is only internally published to the different departments in the Ministry of Water Resources and Irrigation (MWRI) in Egypt and most importantly to the Nile Yield Committee.

Nile Yield Committee

This a standing committee within the Ministry of Water Resources and Irrigation with representatives from the Nile Water Sector (NWS), the Nile Forecasting Center, the High Aswan Dam Authority (HADA), the Irrigation Sector and other sectors and research institutions of MWRI. It meets on a monthly basis, or more frequently as circumstances demand, especially prior to and during the flood season to review the flood forecasts and adjudicate on operational decisions. In addition to NFC, other sectors in MWRI such as NWS and HADA also make forecasts of inflows to Lake Nasser for short-term operational decisions using simple regression techniques. The lead time from the monitored river station at Eddeim on the Blue Nile is of the order of 17 days. Depending on the water level of Lake Nasser, and the expected flows, the committee may take measures to discharge water from the reservoir or open the Toshka spillway to accommodate high expected floods, or to cut some supplies if some drought is expected.

International and transboundary scales:

Although there is no institution that coordinates the management of water resources of the entire river basin area, there are a large number of international institutions and initiatives, identified in the deliverable 6.1, that partially include analysis of drought processes as it is a common factor to many transversal problematic.

More specifically, there are numerous international institutions working on food prevention and humanitarian prevention platforms, which use drought monitoring indicators, for identification of the more problematic situations: the FEWS NET (Famine Early Warning Systems Network), the GIEWS/SMIAR (FAO Global Information and Early Warning System on Food and Agriculture), the WFP (United Nations World Food Programme), the OCHA (Office for the Coordination of Humanitarian Affairs), HIC (Humanitarian Information Centres), the ECHO (European Community Humanitarian Office) and the RELIEFWEB (United Nations website providing information to humanitarian relief organizations), which are all grouped into the RCPA (Food crisis prevention network), an exchange and decision support platform created in 1985 under the initiative of the CSAO/SWAC (Sahel and West Africa Club) and the CILSS (*Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel*). The RCPA publishes collective bulletins related to the West African Food security situation.

3.1.3. What are the societal capacities

As vulnerability to drought has increased globally, greater attention has been directed to reduce the risks associated with drought occurrence through the introduction of planning to enhance operational capabilities such as building institutional capacity, climate monitoring and water supply monitoring.

In July 2011 occurred the driest period in east Africa since 1995 (OCHA, 2011), which caused food crisis in some countries of the African great horn and that threatened the survival of several millions of people. The risks related to drought hazards impose the improvement of drought early warning system and, as a result, risk mitigation will be achieved also to guarantee livelihood of developing countries.

Drops in precipitation during the wet season will affect runoff including stream flow, reservoirs discharges, water levels for lakes and rivers budget. The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Hydrologists are more concerned with how the precipitation deficiency plays out through the hydrologic system including ground water. These impacts depend on intensity and duration of drought which will affect also water demand, agricultural yields and hydropower production. As a result, water available per capita will decrease and several water use dependent activities, including livestock, may be at risk. Hydrological droughts are usually out of phase, with a certain lag, comparing to the occurrence of meteorological and agricultural droughts. In fact, it takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, stream flow, groundwater and reservoir levels. Competition for water in these storage systems escalates during drought and conflicts between water users increase.

Crop water needs will be influenced due to difference between actual and potential evapotranspiration and also the reduction of soil moisture.

Extended drought periods have significant impacts in decreasing crops production or may result, ultimately, in loss of production since weakened plants are more exposed to diseases and insects.

At the end, socioeconomic impacts are correspondent to losses of crop production, livestock production, etc., and food price increases as a consequence.

The societal capacities, in terms of drought preparedness, can be presented through the characteristics of each case study on drought monitoring, forecasting and response, in this last, including the drought mitigation and adaptation practices. Finally, it could be analysed: the existent base data and previous studies for the evaluation of potential impacts of climate change and the possible trends in terms of drought frequency and severity; and, also, the risk assessment issues, including the vulnerability to drought of the case study region.

In what concerns drought monitoring, it was collected information about available data and indices/indicators commonly used (focusing on meteorological, hydrological and agriculture drought effects). Regarding drought forecasting, the main models in use to predict each type of drought and the respective inputs/outputs were identified. To assess the capacity of response, the main stakeholders, involved in drought management process and the corresponding interaction between them, and the mitigation and adaptation practices are presented. During the description of each topic some of the existent problems in the context of drought preparedness are referred.

3.1.3.1. Drought Monitoring

Data collected and main indices/indicators

According to the responses to the Questionnaire for Performance Assessment on Droughts Evaluation, there is a regular drought monitoring evaluation in this case study.

From the available information, and although dependent on a large amount of data, the drought monitoring of the Eastern Nile case study relies essentially on meteorological and hydrological drought indices. On the other hand the base data is adequate, but not always easily available (gaps/limitations on data records, lack of exchange of information and costly data). In fact, regarding data collection and drought monitoring, some problems were observed. For example, in Sudan, one of the countries presented in Nile Basin, the monitoring systems are facing many challenges and problems in terms of purpose, tools, monitoring frequency, data capture and human requirements which may be summarized as follow:

- Data availability, accuracy, reliability;
- Data missing;
- Accessibility to data and information;
- Temporal and special coverage of meteorological stations;
- Lack of appropriate equipment and skilled staff for drought forecasting and monitoring:
    - Poor spatial coverage and limited 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);

The necessary data for drought monitoring (through indices) is: rainfall, temperature, humidity, wind direction and speed, sunshine hours, air pressure, cloud coverage, cloud type and land use data.

In some countries, some additional information is not collected locally due to the lack of appropriate equipment like upper air station, RADAR, etc.

The indices/indicators used to drought monitoring are, then, as follows:

- Meteorological indices
    - Standardised Precipitation Index – SPI
- Hydrological indices/indicators
    - Average discharge at Diem station – Ethiopia
    - Averaged discharge anomalies over JJAS at El Diem station.
    - Mean Average discharge at Khartoum station on the blue Nile – Sudan
    - The average annual nature flow at High Aswan Dam – Egypt

According to the questionnaires responses there is no information about agriculture or socioeconomic indicators.

Risk/Vulnerability Mapping

For this case study it was also possible to conclude the inexistence of any kind of drought risk mapping.

3.1.3.2. Drought Forecasting

Meteorological Drought Forecasting

The main information collected in this topic is presented in Table 4: typical models used, their main characteristics, the inputs, outputs and the lead time of the forecast.

Table 4. Models for meteorological droughts forecast, their characteristics, inputs, outputs and lead time of the forecast , in the Eastern Nile Basin Case Study.

Model	Characteristics	Inputs	Outputs	Lead time of the forecast
ETA Model	State-of-the-art atmospheric model. It has been very successful in regional weather forecast.	Initial and lateral boundary conditions from NCEP GCM.	Surface pressure, horizontal wind components, temperature, specific humidity, turbulent kinetic energy, cloud hydrometeors.	Forecasts up to five days.
MM5 Model	It was designed to simulate or predict mesoscale and regional-scale atmospheric circulation. The model has been very successful in regional climate and seasonal prediction applications.	Initial and lateral boundary conditions from NCEP GCM.	Weather elements.	Forecasts up to five days.
PRECIS	It is a downscaling tool that adds fine scale (high resolution) information. It generates high-resolution climate change information for as many regions of the world as possible.	Initial and lateral boundary conditions from UK Met office.	All the climate variables: rainfall, temperature, wind.	Monthly, seasonal, annual, decadal (Daily and hourly averages can be selected if required).
Numerical Weather Prediction (NWP)	It provides predictions on many atmospheric variables. The NWP method is flawed in that the equations used by the models to simulate the atmosphere are not precise.	N/A	Precipitation, temperature, relative humidity, solar radiation and many others.	N/A
RegCM4.1	It is a regional climate model, suitable to study the tale	Initial and lateral boundary data +	Surface variables, radiation variables and atmospheric	Depend on the data used for the boundary

Model	Characteristics	Inputs	Outputs	Lead time of the forecast
	connections through the band version. The model is very successful in dynamical down scaling.	SST.	variables.	condition.

According to the information provided, the Eastern Nile case study has a significant flexibility in terms of lead time of the forecasts, ranging from some days to several months.

Hydrological Drought Forecasting

The main information collected on this topic is presented in Table 5: typical models used, their main characteristics, the inputs, outputs and the lead time of the forecast.

Table 5. Models for hydrological droughts forecast, their characteristics, inputs, outputs and lead time of the forecast, in the Eastern Nile Basin Case Study.

Model	Characteristics	Inputs	Outputs	Lead time of the forecast
Nile Forecast System (NFS) (that includes also the ESP model, responsible for the forecast)	It is a near real-time distributed hydro-meteorological forecast system. This model produces possible monthly runoff traces, which are subsequently disaggregated to daily data.	Rainfall and potential evapotranspiration.	Monthly runoff traces.	About 3 month.
RIBASIM-NILE	It is a river basin simulation model (simulation of the water distribution). The model compares the total demand of a node with the satisfied demand, and then defines the shortage.	Inflows at the different nodes (inflow data series or as rainfall data series).	N/A	N/A
HAD-DSS	It simulates the behaviour of Lake Nasser. The model processes the inflow data combined with	Inflow to Lake Nasser.	N/A	Support real time operation; week/10day/month.

Model	Characteristics	Inputs	Outputs	Lead time of the forecast
	the operation rules of the dam to provide output time series for release, energy production, reservoir level and storage at Lake Nasser as well as any spillage.			

From provided information, it was possible to verify that the Eastern Nile case study relies on the RIBASIM model, among others. Nevertheless, RIBASIM is used to simulate water balances for planning purposes only. In fact, it should be noted that only NFS has forecasting features, since the others are models that use the information provided by meteorological forecasting to simulate hydrological parameters.

Agriculture Drought Forecasting

This case study did not provide any information related to agricultural Drought Forecasting.

3.1.3.3. Drought Response

Main stakeholders

The main stakeholders (entities/ authorities) responsible for drought management process in the Eastern Nile Case Study are:

- National Meteorological Services Agency (NMSA), Ethiopia;
- Sudan Meteorological Authority (SMA), Sudan;
- Higher Council for Civil Defence, Sudan;
- Ministry of Water Resources and Irrigation (MWRI), Egypt
- Nile Forecasting Centre (NFC), Egypt;
- Egyptian Meteorological Authority (EMA), Egypt.

The Meteorological Agencies, such as NMSA, SMA and EMA, are responsible for providing forecasts of meteorological and hydrological droughts to the responsible ministries.

The Sudan Meteorological Authority and Ministry of Irrigation and Water Resources provide advice to policy makers in all issues about climate and weather and provide data and information for public use, scientific research and farmers. The Sudan Meteorological Authority has field teams assigned to help farmers with seasonal crops and drought preparedness / response (is it not clear if they are ensuring that job presently). Farmers give feedback to the SMA providing reports on rain/drought seasons and accuracy of forecast.

Even though the resources (human and technical) are limited, some efforts are being made to minimize the drought impacts

Drought mitigation and adaptation practices

The identification of drought mitigation and adaptation measures implemented in Eastern Nile basin was based on the experiences of the Sudan, Ethiopian and Egypt countries.

- **Mitigation Measures**

According to the information available in deliverables D 2.2 and D 2.5 the main types of drought mitigation measures implemented during the historical droughts in these countries are presented in Table 6, according to the specific sector of application and to the type of measures.

Table 6. Compilation of drought mitigation measures implemented in Eastern Nile Case Study.

Sector	Type of measures	Description
Transversal measures	Social support	Ensure food Security
		Mobilizing social support and claims
Agriculture	Demand/Supply management	Mitigate drought impacts through irrigation.
		Distribute necessary tools and equipment.
		Use of drought resistant crops.
		Community seed saving and construction of grain storage.
		Training of local communities and farmers on mitigation measures.
		Identify communities most affected by drought.
		Support regeneration of vegetative cover.
		Agroforestry farming.
Pastoral-livestock	Impact management	Construction of grain storage.
		Providing water through emergency sources.

- **Adaptation Measures**

Similarly, the main types of drought adaptation measures implemented in these countries are presented in Table 7, according to the specific sector of application and to the type of measures.

Table 7. Compilation of drought adaptation measures implemented in Eastern Nile Case Study.

Sector	Type of measures	Description
Transversal measures	Social support	Income generation from non-pastoral activities
	Water management	Develop the techniques of conservation and storage of water in particular allowing to face the risks of dryness in the vulnerable areas (e.g. construction of small scale dams).
		Increase irrigation water use efficiency and agricultural productivity in old lands.
		Survey and monitor the locations and impacts of industrial pollutants discharged to the water resources
Agriculture	Demand/Supply management	Provide technical packages for the farmers and local communities (such as best crop varieties (more resistant), land preparation, planting methods, technologies and fertilizer application).
Pastoral-livestock	Demand/Supply management	Herd splitting and distribution.
		Diversification of species.
		Livestock accumulation and changing herd/species composition.
		Forage supplementation.
		Generation of food stores.
		Reduction of food intake and changing composition of diet.
	Drought recovery	Drought recovery strategies.
	Social support	Income generation from non-pastoral activities.

The Eastern Nile Case Study has lower capacity/resources than state-of-the-art experience, in terms of mitigation measures. The Eastern Nile experience is mainly targeted to minimize the impacts of droughts in agriculture and pastoral-livestock, rather than to prevent possible drought impacts.

In what concerns adaptation measures, some actions from the state-of-the-art experience, could be highlighted as useful for Nile Case Study, namely in what regards the development of early warning systems, drought monitoring and forecasting information systems and the monitoring of balance between water availability and water demand. About agriculture, some measures could be implemented to improve African drought preparedness (in addition to the ones already used), such as, the use of terracing practices, promote research and development, change sowing dates (plant two crops instead of one) and governmental help to farmers.

The reality of Eastern Nile case study, in terms of needs, capacities, and technical and financial resources, is different from the state-of-the-art, although some actions could be taken, based on these best practises, to improve the African preparedness to droughts.

3.1.4. Identification of risks increase on future drought hazards

Climate Change Impact

There are some previous climate studies that should be considered:

- Eltahir, E. A. B., 1996. El Niño and the Natural Variability in the Flow of the Nile River, Water Resources Research, 32(1): 131-137.
- Amarasekera, K. N., R. F. Lee, E. R. Williams and E. A. B. Eltahir, 1997. ENSO and the Natural Variability in the Flow of Tropical Rivers, Journal of Hydrology, 200(1): 24-39.
- Eltahir, E. A. B. and G. Wang, 1999. Nilometers, El Niño and Climate Variability, Geophysical Research Letters, 26(4): 489-492.
- Wang, G. and E. A. B. Eltahir, 1999. Use of ENSO Information for Medium- and Long-range Forecasting of the Nile Floods, Journal of Climate, 12(6): 1726-1737

From these studies it can be concluded that:

1. The analysis of the Nile flow and ENSO index suggests that natural variability in the annual flow of the Nile River can be decomposed into two components: a mean that varies in time following ENSO, and a random fluctuation that occurs around the varying mean due to climatic factors other than ENSO. The fact that ENSO events can be predicted with reasonable accuracy at a lead time of about 1 year suggests that the correlation between ENSO and the Nile flood should be used to improve the predictability of the annual flow in the Nile River.
2. Also, the annual discharges of the Nile River and two tributaries of the Nile, the Blue Nile and Atbara rivers, are strongly correlated to ENSO. The Blue Nile and Atbara, but not the White Nile, are responsible for the ENSO signature observed in the total Nile River discharge measured at Aswan. Inclusively, the incorporation of the rainfall and river flow

information in addition to the ENSO information significantly improves the quality of the medium-range forecasts.

3. On the other hand, the frequency of El Niño years during the last two decades is the highest for this century. The same frequency is also significantly high compared to the long-term statistics. The corresponding return period is about 450 years. Such a high frequency of El Niño years was never sustained for more than a few decades. If frequent El Niño years are now possible to be sustained for more than a few decades, then such an episode would present a clear sign of a significant change in the global climate.

On the other hand, under the scope of DEWFORA (as described in Deliverable D6.2), the impact of climate change on the Eastern Nile basins was studied by NFC. For the future climate, dynamically downscaled rainfall from an ensemble of 6 simulations is used. These were produced by the **PRECIS regional climate model (RCM)**.

- **RCM Simulations**

The PRECIS regional modelling system developed by the UK Met Office (UKMO) / Hadley Centre has been used in this study to project future climate. This application considers uncertainties in the regional climate response to global climate change through the construction of an ensemble of 6 RCM runs, but not those arising from different emissions scenarios nor those arising from different downscaling methods (e.g. different RCMs or statistical methods).

RCM Description: A regional climate model (RCM) is a high resolution climate model that covers a limited area of the globe, typically 5,000 km x 5,000 km, with a typical horizontal resolution of 50 km. RCMs are based on physical laws represented by mathematical equations that are solved using a three-dimensional grid. Hence RCMs are comprehensive physical models, usually including the atmosphere and land surface components of the climate system, and containing representations of the important processes within the climate system (e.g., cloud, radiation, rainfall and soil hydrology).

PRECIS Development: The National Communications Support Unit (NCSU) of UNDP is developing an integrated package of methods to assist developing countries to develop adaptation measures to climate change. Assessments of vulnerability are informed by estimates of the impacts of climate change, which in turn are often based on scenarios of future climate. These scenarios are generally derived from projections of climate change undertaken by Global Climate Models (GCMs). These GCM projections may be adequate up to a few hundred kilometres or so, however they do not capture the local detail often needed for impact assessments at national and regional levels. One widely applicable method for adding this detail to global projections is to use a regional climate model (RCM). Other techniques include the use of higher resolution atmospheric GCMs and statistical techniques linking climate information at GCM resolution with that at higher resolution or at point locations.

Regarding the mains results, **Error! Reference source not found.** shows the impact of climate change on the cumulative frequency distribution of the rainfall over the Blue Nile and Atbara sub-catchments. The distributions of the ERA40 are higher than those of both CRU and NFS datasets for both sub-catchments resulting from the overestimation shown above. The CRU deviates from the NFS for high rainfall (at 20% probability of exceedance) but the distributions are very close elsewhere indicating similar probabilities for droughts. The distributions of the PRECIS rainfall (shown as a range from the 6 simulations) take the shape of the ERA40-PRECIS with slight increase in the future for both basins (about 6% on average for both basins). This further indicates that the source of the bias is the RCM itself.

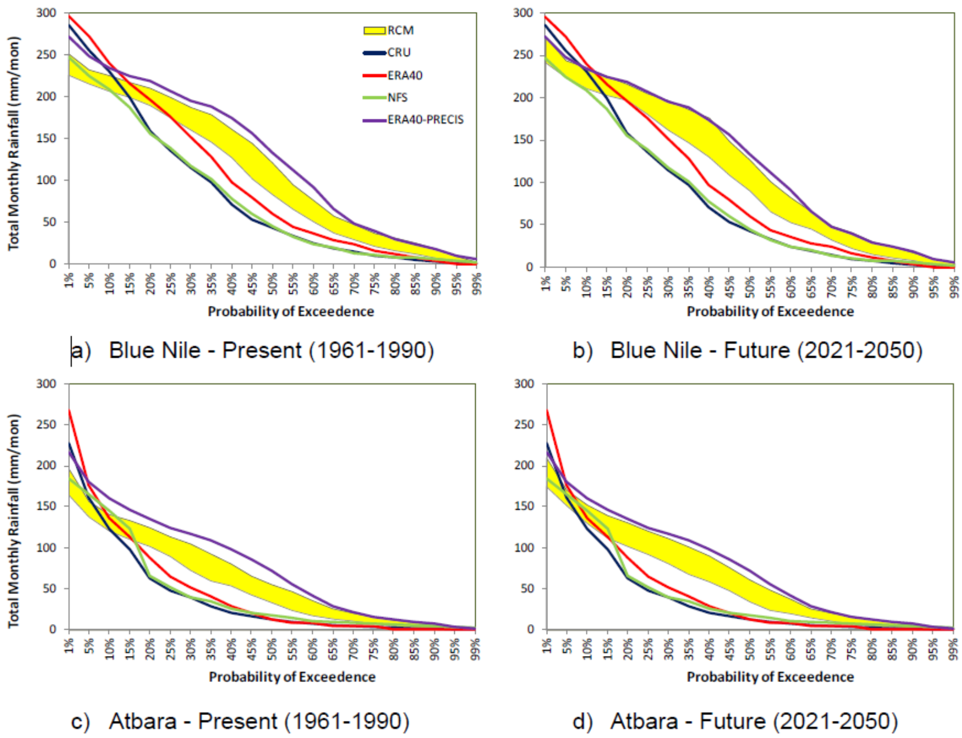


Figure 5. Impact of Climate Change from 6 RCM Simulations on Rainfall Frequency Distribution of the Blue Nile and Atbara. (The yellow band indicates the range across the 6 PRECIS simulations)

Because the SPI normalizes rainfall, SPI distributions of all three observed datasets (CRU, ERA40, and NFS) in addition to the ERA40 PRECIS simulation take similar shapes as shown in **Error! Reference source not found.** for annual SPI series calculated over the hydrologic year (August to July). Climate change as depicted by the 6 PRECIS simulations raises the whole distribution indicating more rainfall over all probabilities, especially for the Blue Nile. For the Atbara, though, the uncertainty (as indicated by the bandwidth) seem to increase at the low end of the distribution indicating that some scenarios still predict increases in drought despite the general increase in rainfall.

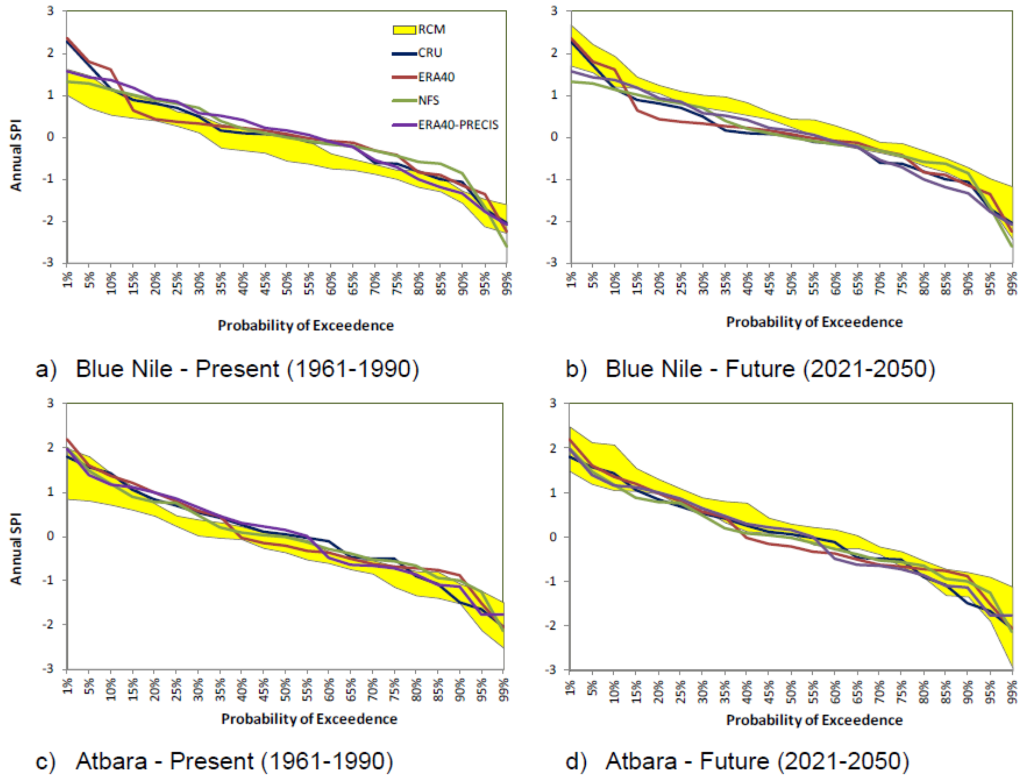


Figure 6. Impact of Climate Change from 6 RCM Simulations on Hydrologic Year SPI Frequency Distribution of the Blue Nile and Atbara.

Through the SPI distributions calculated for 1, 3, 6, 9, and 12 months in sequence, the probability distributions shift upwards in the future indicating more rainfall over the different probability bands, however, with some increases in both flood and drought probabilities at the edges of the distribution i.e. increased probability of extremes.

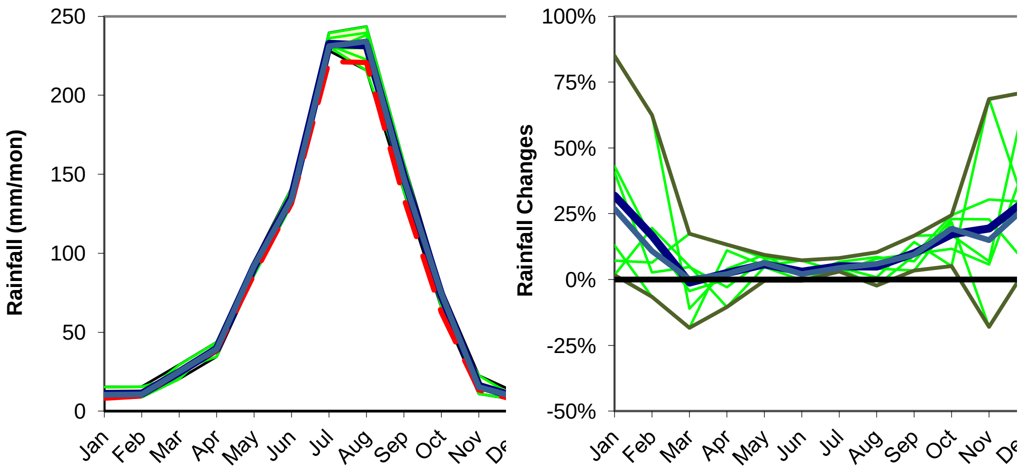
The main conclusions regarding the current set of climate simulations indicate a general increase in rainfall over the region but this does not exclude the increase of drought probability for some lead times especially longer ones and on the scale of the hydrologic year. The uncertainty bandwidth (defined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

Moreover, NFC studied also the impact of climate change on the Eastern Nile basins in terms of: rainfall, evapotranspiration, temperature, and flow at the outlet location of Blue Nile and Atbara. In this study, six ensembles are selected from 17 runs of HadCM3 GCM model, also downscaled by Regional Climate Model (PRECIS) during the period 1961-1990, the base period, and 2021-2050, the future period.

The NFS performance for the Blue Nile at Khartoum, Figure 7e, representing the whole basin is very good in terms of overall agreement of hydrograph shape, time series, and volume bias (1.8% for Khartoum).

In terms of climate change impacts for whole basin at Khartoum,

Figure 7, changes in rainfall vary from 0-30% at average ensemble monthly time scale, but are rather modest (5-10%) for the whole basin in terms of annual totals. Changes in PET (Potential Evapotranspiration) are also small, in the order of 5% in monthly and annual totals.



a) Rainfall b) Rainfall changes

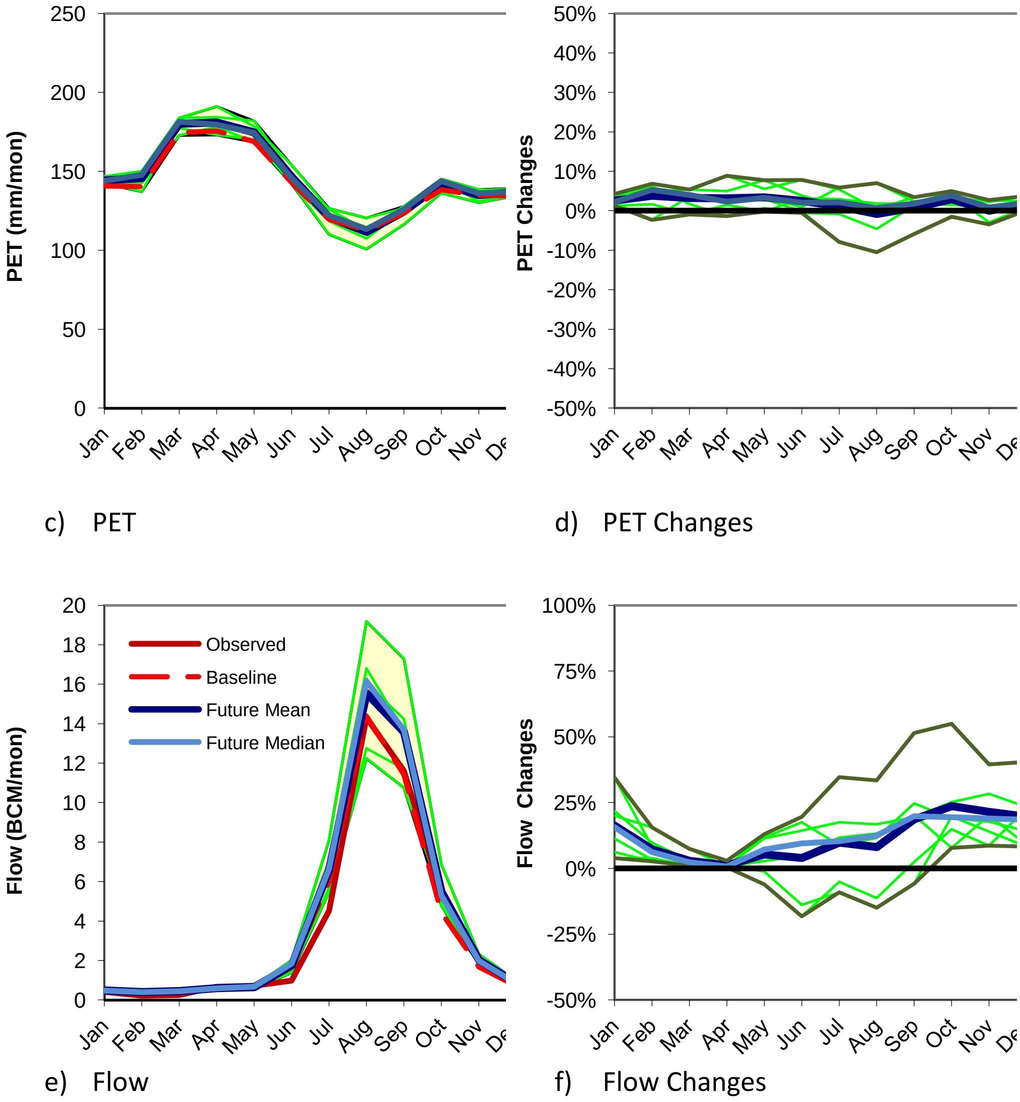
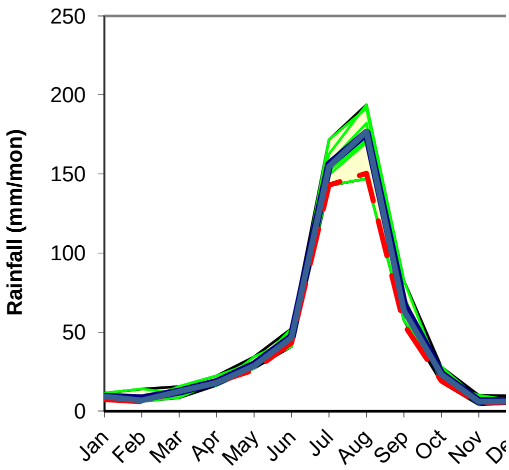


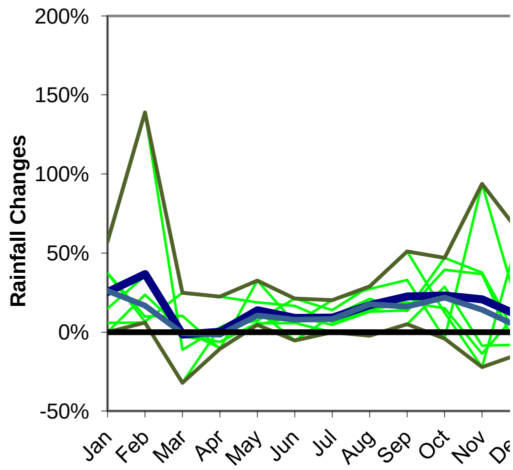
Figure 7. Changes in the sub-catchment rainfall and PET and flow of the Blue Nile Basin at Khartoum from 6 RCM ensemble members. The thin green lines show the different RCM ensemble members while the thick green lines show the range.

The general tendency of rainfall increase and PET increase is translated as a general tendency to produce increases in flow but the signal is rather mixed especially as two ensemble members project reductions (up to 50% at monthly level, Figure 8f, and 6% for both stations at the annual level) while the rest of models report increases up to 29% and 39% for Diem and Khartoum respectively at the annual level. Diem and Khartoum are the two station in analysis.

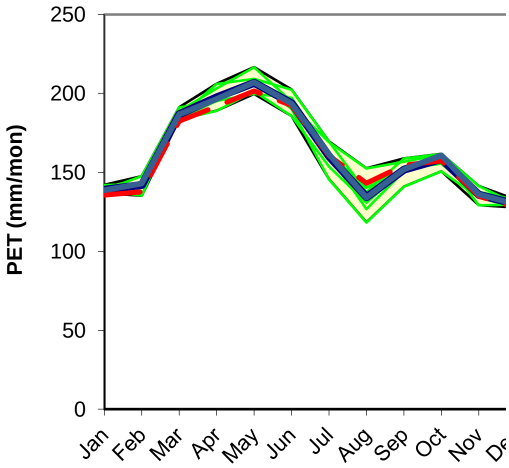
For Atbara river basin, there is a general consensus across all 6 ensemble model simulations for rainfall increase ranging between 0-40% at monthly average ensemble values (Figure 8 a, b) and 3.5% and 21% in terms of annual totals. In terms of PET, there is consensus on increases during the dry season and reductions during the wet season, reinforcing the effect of rainfall increases. The increase in the dry season has minor effects on the flow as PET cannot be satisfied (Figures 8c, e). Summarized over the whole year, the annual total PET changes are small ranging from -1.7% to +3.3%.



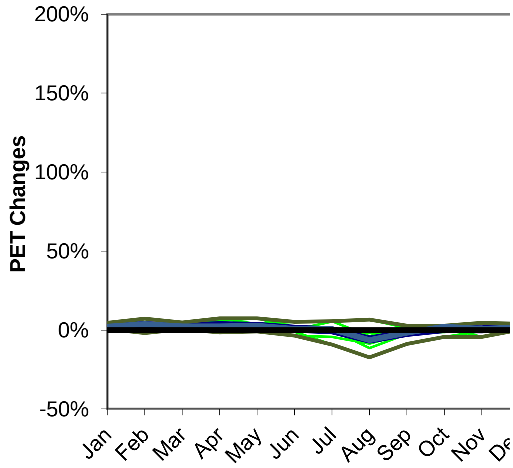
a) Rainfall



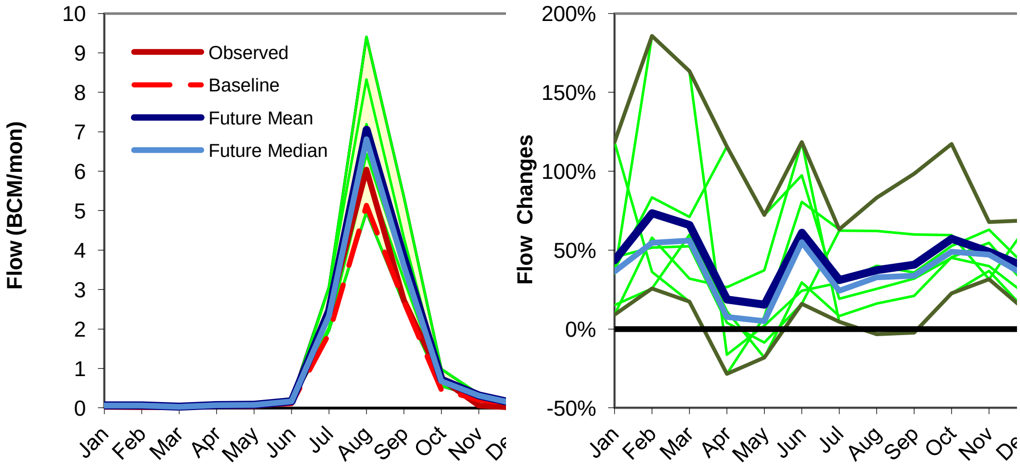
b) Rainfall changes



c) PET



d) PET Changes



e) Flow f) Flow Changes

Figure 8 Changes in the sub-catchment rainfall and PET and the flow of the Atbara Basin at its mouth from 6 RCM ensemble members. The thin green lines show the different RCM ensemble members while the thick green lines show the range.

The relatively large increases in rainfall combined with a tendency of PET reduction during the wet season are translated into relatively large increases in flows, especially during the wet season (Figure 8e, f) ranging between 2 and 83% in annual totals. This range should be treated with caution as baseline simulation shows underestimation of flow. The hydrographs are scaled up for the different ensemble members with no changes in peak times.

3.1.5. Identification of local concerns expressed by Stakeholders

The local concerns expressed by Stakeholders focus on two main aspects: organizational and technical issues. Based on those concerns the main needs on each category (data related, drought early warning systems, drought monitoring, forecasting and response, and climate change effects on drought risks) were identified.

Regarding data related concerns, it was referred the need to improve the coordination of stakeholders and data sharing and to provide a higher density and data quality of monitoring (meteorological and hydrological) networks, e.g. fostering the use of satellite data for gaps fill.

In what concerns drought monitoring it is considered essential to integrate monitoring systems, based on multiple indicators, for detecting the early onset and end of droughts and develop and test a model to assess the impacts of droughts on agriculture.

On drought forecasting the main identified requirements are the improvement of operational and institutional capabilities (e.g. improving meteorological forecasts and fostering the background of institutional staff and decision makers for better understanding and use of those forecasts) and also the provision of more reliable and specific information (e.g. for farmers use).

The drought response is the most critical point, and the success will result from an adequate preparation. On this topic it is referred as important to promote government and scientific community involvement; improve guidelines on communication to/with media; define mitigation and adaptation strategies for short, medium and long term preparedness; increase emphasis on drought policy, preparedness and mitigation and society's capacity; and identify the vulnerability factors.

On climate change effect assessment the main need focuses on coupling weather forecast and projected climate change simulations with a hydrological model through the application of downscaling and bias-correction methods.

3.2. Case Study 6.4 – Niger

3.2.1. General characteristics

The Niger Basin is the third longest river in Africa (4 180 km) and its basin (2 117 700 km^2) encompasses nine countries in West and Central Africa. The countries of the Niger River Basin are: Algeria, Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger and Nigeria. About 30% of the basin is located in Mali, one of the poorest countries in the world. The main economic activities in Mali are agriculture and fishing. The agricultural sector employs about 80% of the work force, even though less than 2% of the land is arable. For this reason, livelihood and welfare in Mali depends largely on the timely onset and intensity of the annual monsoon. The Niger Basin can be divided into five main hydrographic regions, namely: Upper Niger Basin, Inner Niger Delta (IND), Middle Niger Basin, Lower Niger Basin and Maritime Niger Delta, Figure 9. As referred in Deliverable D6.1, the DEWFORA project is focused on the Inner Niger Delta region (entirely situated in Mali) which is highly dependent from the hydrological contributions of the upstream catchment.

Figure 9. The Niger Basin, its five main hydrographic regions and the case study area within the circle.

Source: BMZ - Federal Ministry for Economic Cooperation and Development and KFW entwicklungsbank (2010)

The case study focus scale: The Inner Niger Delta

- **Impacts of drought situations**

Apart from a prospected climate change, there is a high inter-annual variation in Sahelian rainfall, leading to a high variation in the area annually flooded. Partly this means, that people and communities are already used to adapting to varying circumstances as is the highly resilient ecosystem of the IND. However there are some severe drought periods, leading to extreme low flows (like in the 1970s and 1980s). In the Inner Niger Delta, the decreases of flood height, flood coverage and flood durations have detrimental impacts on many sectors of activities (Zwarts *et al*., 2005). Fishing sector is less productive as the regeneration of the fish population is altered leading to a decrease of fish capture and overfishing practices (Quensière, 1994). The livestock herding sector loses many rich pastureland and fodders leading to overgrazing phenomena (Marie *et al*., 2007). For the farming sector, the usable area for agriculture is drastically reduced (Liersch *et al.*, 2011). The combined pressure exerted from the various competing sectors impacts as well protected ecosystems and ecological habitats hosting a rich fauna and flora like migratory birds (Zwarts *et al.*, 2005). During such disaster years, the communities of the Inner Niger Delta, largely exposed to poverty, cannot withstand exposure to climate shock and stress and therefore have hardly any other option than to deplete all available natural resources. The problematic is then to overcome these disaster years. Associated with climate change and upstream water management pressures, processes of overcultivation, overgrazing and deforestation leading to soil erosion and desertification are aggravated. The impact in future disaster year are also expected to be much larger than before, given the population growth and growth of the herds of cattle (Goulden and Few, 2011).

While the pessimistic view prevails, some researchers suggest that Sahelian farmers and herders have a much better capacity for adapting to population pressure and climate variability than previously thought (Barbier *et al.*, 2008). Proof of soil fertility decline is unconvincing, and yields have not declined as the pessimists predicted. When famines have struck, they have been more the result of bad policies than of local communities' incapacity to deal with new challenges. Emphasis is usually placed on local knowledge rather than external transfer of technology. Both climate irregularity and population density can be overcome. Many semi-arid countries in the world are neither poor nor vulnerable. Also, densely populated areas are often more likely to be able to sustain investment in land conservation and risk reducing techniques. However, so far, among the development pathways proposed for the Sahel, no clear winner has been identified (Barbier *et al.*, 2008). Drought mitigation and adaptation practices can provide multiple benefits to the extent that they contribute to development in general by reducing investment risk. However, crisis interventions can be counter-productive if they create a dependency syndrome or compete for resources from other activities with longer term benefits. Reducing risk can have then strategic importance.

3.2.2. Institutional Framework

For coping with droughts the Mali Government set up a number of commissions specific to deal with different types of disasters, including droughts. The current set of these commissions is:

- An Inter-Ministerial Commission on Droughts Management, led by the Prime Minister;
- A Technical Committee including Ministries, the United Nations Agencies ,Embassies, and International Organizations;
- National Cells including a Forecasting Component, an Emergency/ Rehabilitation Action Component, and an Evaluation Component, depending on the category of the disaster;
- Monitoring Cells attached to key-Ministries involved, with monitoring committees at the regional level, Circle (Territorial Division) level and at the level of Communes, depending on the nature of the disaster;
- The State`s structures and /or sectorial Departments in charge of the day-to-day management of risks and disasters Prevention and management, with lead

institutions, depending on the nature of the disaster (Epidemics, Epizootics, locust invasions, floodings, drought , etc.).

International and transboundary scales:

As referred for the Eastern Nile Case Study, a large range of international institutions and initiatives integrating drought monitoring, forecasting and responses were identified in the deliverable 6.1. It is possible to identify three main transversal thematic in which drought assessment plays a key role:

- **Food crisis prevention**

There are numerous international institutions working on food prevention and humanitarian prevention platforms using drought monitoring indicators and approaches, as detailed for the Eastern Nile case study: the FEWS NET (Famine Early Warning Systems Network), the GIEWS/SMIAR (FAO Global Information and Early Warning System on Food and Agriculture), the WFP (United Nations World Food Programme), the OCHA (Office for the Coordination of Humanitarian Affairs), HIC (Humanitarian Information Centres), the ECHO (European Community Humanitarian Office) and the RELIEFWEB (United Nations website providing information to humanitarian relief organizations), which are all grouped into the RCPA (Food crisis prevention network), The RCPA publishes collective bulletins related to the West African Food security situation.

- **Weather forecast application**

Three main institutions concentrate their expertise on West African weather and climate:

- ACMAD (Weather and Climate Centre with African continental competence)
- CRA (*Centre Regional Agrhymet*) specialized institute from CILSS
- AMMA (African Monsoon Multidisciplinary Analyses)

The West Africa’s Seasonal Outlook Forum, PRESAO brings together scientists and hydrologists from National Meteorological and Hydrological Services (NMHSs), and climate forecasting centres from across the region (ACMAD, AGRHYMET) and the world (AMMA, Met Office, Meteo France, the International Research Institute for Climate and Society (IRI), the National Oceanic and Atmospheric Administration Africa Desk, the World Meteorological Organization), to discuss and agree on the forecast for the July-August-September rainy season over west

Africa. The PRESAO was established in 1998, and has occurred annually each May to provide a consensus forecast for the coming July September rainfall season (Hansenet *et al.*, 2011).

- **Integrated river basin management**

The NBA - Niger Basin Authority (*Autorité du Bassin du Niger*) is one of the oldest African Intergovernmental Organizations created in 1964 in its original form which was the River Niger Commission. Its mission is to promote cooperation between the member countries and to ensure the sustainable development of the River Niger Basin. The new NBA Partners Cooperation framework was signed by NBA 22 technical and financial partners in April 2004.

The NBA created a Master Plan for Development and Management of the Niger Basin under the Action Plan for the Sustainable Development of the Niger Basin (SDAP) (BRL and DHI, 2007) which translates the 2025 Shared Vision into tangible actions to alleviate poverty, protect the Niger Basin environment and strengthen cooperation between NBA member countries. The definition of the shared vision was adopted in 2005 by the NBA council of ministers: "The Niger Basin, a shared region of sustainable development achieved through the comprehensive, integrated management of water resources and their associated ecosystems, to improve everyday living standards and prosperity by 2025”. The challenges to create an international legal framework for a shared river basin management vision and transboundary cooperation with the mandate of the Niger Basin Authority institution are outlined in Andersen *et al.* (2005).

One of the priorities also presenting in the SDAP is the information collection, processing and reporting of hydrological and river basin management monitoring and measurements. The improvement, the harmonization and the consolidation of hydrological and meteorological measurement and databases are the object of several past and present initiatives (HYDRONIGER, Niger-Hycos, SIEREM, WASCAL, as described in deliverable 6.1) launched in collaboration with the Niger Basin Authority and affiliated state members.

3.2.3. What are the societal capacities

As mentioned for the Eastern Nile Case Study, the societal capacities for Niger Case Study in terms of drought preparedness can also be presented through the characteristics on drought monitoring, forecasting and response.

3.2.3.1. Drought Monitoring

Data collected and main indices/indicators

According to the responses to the Questionnaire for Performance Assessment on Droughts Evaluation, in this case study there is a regular drought monitoring evaluation.

Regarding data collection and drought monitoring, some problems were identified and, in this context, it is necessary: to improve data quality and availability, increase of continuous monitoring and data collection, foster use of satellite data for gaps fill, improve the coordination between projects, programs, organizations, stakeholders and scales and, improve the coordination between the different institutions working on droughts.

The necessary data for drought monitoring (through indices) is: wind speed and direction; temperature; insulation; evapotranspiration; rainfall; flood height; river discharge; flood duration; monitored rainfall, discharge and water levels; flood extent from satellite imagery; national to regional statistical census; and reservoir and irrigation schemes management information.

Due to the limitations above mentioned, it is not explicit if the the indices/indicators referred as used in Niger case study for drought monitoring are, obtained in a regular basis. Nonetheless, according to the information available, the indices/indicators referred as used in Niger case study are, as follows:

- Meteorological indices
  - Rainfall Anomaly Index – RAI
  - Standardised Precipitation Index – SPI
  - Evapotranspiration Deficit Index – ETDI
  - Reconnaissance Drought Index – RDI
- Hydrological indices
  - Discharge Anomaly Index – DAI
  - % from the flow duration curve
  - Mean annual minimum flow
  - Recession indices – RI
  - Standardized Runoff Index – SRI
  - Base flow indices – BLI
  - Standardized Discharge Index – SDI
  - Regional Stream flow Deficiency
  - Aggregate Drought Index – ADI

- Agriculture indices
    - Normalized Difference Vegetation Index – NDVI
    - Vegetation Drought Response Index – vegDRI
    - Normalized Multi-Band Drought Index – NMDI
    - Soil moisture budgeting
    - SWI (Standardized Water Level Index) in the Inner Niger Delta
    - SFI (Standardized Flood Index) in the Inner Niger Delta
    - Soil moisture Index
    - Moisture availability index
    - Generalized Monsoon Index (GMI)
    - Yield moisture index (YMI)
- Socioeconomic indices
    - National/Regional GDP growth
- Others
    - Hydropower production and water volume in reservoirs of Sélingué and Sotuba
    - Water diversion to irrigation schemes
    - National/Regional agricultural production
    - National/Regional Fish capture
    - Regional water birds census
    - Regional total number of livestock

<u>**Risk/Vulnerability Mapping**</u>

For this case study it was possible to identify the existence of **two distinct types** of **drought risk maps**. On one hand there are <u>global risk maps</u> provided by several global drought early warning systems (FEWS NET Africa Data Portal; Early Warning Explorer Model (EWX); USDA Crop Explorer, etc.) that provide alerts for governmental and NGO's decision level, but are not sufficiently detailed to support local stakeholders decision making. On the other hand, there are <u>local drought risk maps</u> developed by local communities, but only in the frame of specific projects, and not regularly, reason why they are not useful for stakeholders needs.

3.2.3.2. Drought Forecasting

Meteorological Drought Forecasting

The typical models and its characteristics used in meteorological drought forecasting, and the ones under study in DEWFORA project, are presented in Table 8, according to the available information.

Table 8. Models for meteorological droughts forecast, their characteristics, inputs, outputs and lead time of the forecast, in the Niger Case Study.

Model	Characteristics	Inputs	Outputs	Lead time of the forecast
ECMWF - ERA-Interim	ERA-Interim (ERAI) is the latest global atmospheric reanalysis produced by ECMWF. The dynamical core of the atmospheric model is based on a spectral representation for the basic dynamical variables, a hybrid vertical coordinate, and a semi-Lagrangean semi-implicit time stepping scheme. It provides weather forecast products.	Variational analysis of the basic upper-air atmospheric fields (temperature, wind, humidity, ozone, surface pressure), followed by separate analyses of nearsurface parameters (2 m temperature and 2 m humidity), soil moisture and soil temperature, snow, and ocean waves.	Daily precipitation, temperature, relative humidity, solar radiation.	32 days
CSIR CCAM	The conformal-cubic atmospheric model (CCAM) as seasonal forecasting system is currently being run operationally at the Council for Scientific and Industrial Research (CSIR) in South Africa. It provides weather forecast products.	N/A	Daily precipitation, temperature, relative humidity, solar radiation.	1 month

Additionally, there are other models referred as used in meteorological forecasting, namely, PRESAO, IRI Weather Forecast, IBIMET Sahel resources and Météo France/G-eau ARPEGE.

Hydrological Drought Forecasting

The main information collected on this topic is presented in Table 9: typical models used, their main characteristics, the inputs, outputs and the lead time which is possible to do the forecast, according to the available information.

Table 9. Models for hydrological droughts forecast, their characteristics, inputs, outputs and lead time of the forecast, in Niger Case Study

Model	Characteristics	Inputs of data needed	Outputs	Lead time of the forecast
SIP (*Système Informatique de Prévision*) - Niger basin Authority	It aims to predict in advance the flood based on the information provided by a network of hydrometeorological stations.	N/A	N/A	N/A
PCR-GLOBWB	It is a grid-based model (coded in PCRaster) of global terrestrial hydrology.	Precipitation, actual evapotranspiration, snow and ice dynamics.	Daily discharge and water balance.	N/A
SWIM	It is a comprehensive GIS-based tool for hydrological and water quality modelling in mesoscale watersheds. Semi-distributed, process based, daily time step, Muskingum routing, curve number method.	Daily precipitation, air temperature and relative humidity and solar radiation, GIS for topography, soils, land cover, Data for crop and dam management.	Daily discharge and water balance, hydropower generation, flood propagation in the Inner Niger Delta.	1 month
OPIDIN	It is a peak and flood propagation statistical prediction model. Based on water level time series from 1956-2007 in the Inner Niger Delta. Can be easily used by stakeholders to read prediction on site.	Water level time series and current water level in five specific stations.	Period and level for the annual peak water level and the interval of confidence for three stations. Correlated flooding map.	1 to 2 months

Note: Obviously, being mainly correspondent to water balance models the forecasting capabilities of PCR-GLOBWB and SWIM are dependent on the meteorological forecasts possible to be obtained as inputs.

Agriculture Drought Forecasting

The main information collected on this topic is presented in Table 10: typical models used, their main characteristics, the inputs, outputs and the time in advance which is possible to do the forecast, according to the available information.

Table 10. Models for agricultural droughts forecast, their characteristics, inputs, outputs and lead time of the forecast, in Niger Case Study

Model	Characteristics	Inputs	Outputs	Lead time of the forecast
Water Balance model	It follows the balance that is normally determined for a volume of soil, following the principles of the of mass conservation law : any change in the water content of the soil during a specific period of time is equal to the difference between the amount of water added to and withdrawn from the soil volume.	N/A	N/A	N/A
Thornthwaite	N/A	N/A	Relative evapotranspiration and relative water deficiency.	N/A
Mather	N/A	N/A	Relative evapotranspiration and relative water deficiency.	N/A

Note: Obviously, being mainly correspondent to water balance models the forecasting capabilities of the models referred are dependent on the meteorological forecasts possible to be obtained as inputs.

3.2.3.3. Drought Response

To avoid overexploitation of natural resources and, in a worst-case, famine with associated socio-economic difficulties, potential options from (inter)national to community levels for drought mitigation and adaptation practices were listed with the support of scientific literature and of stakeholder platform. For the community level responses, it is possible to refer the works of Barbier *et al.* (2008) and Djoudi *et al*. (2012) to broaden the scope of adaptive mitigation and adaptation practices in order to initiate debates for their effectiveness along the different DEWFORA stakeholder workshops organized by Wetlands International.

Main stakeholders - Mali

Since the promulgation of the biological diversity convention in 2001, the Republic of Mali agrees that "drought phenomena and ecosystem deterioration must systematically be considered in planning processes in economic, social and cultural development". Also, in the "*Programme d'Action National d'Adaptation aux Changements Climatiques*" promulgated in 2007, drought hazard is identified as the highest climatic risk in the country. In Mali, drought monitoring, forecasting and response are trans-sectorial issues concerning a large range of administrative levels and entities. Drought problematic comprises the responsibility of more than six ministries (Energy, Mines and Water; Agriculture; Breeding and Fishing; Forestry; Inner Affair and civil protection) with associated ministerial agencies (National meteorological agency (*Direction Nationale de la Météorologie* - DNM), Niger river basin agency (*Agence du Bassin du Fleuve Niger* - ABFN), Environment and sustainable development agency (*Agence de l'Environnement et du Développement Durable* - AEDD), National hydraulic agency (*Direction Nationale de l'Hydraulique* - DNH). Forming an interministerial Food Security Committee (*Commissariat à la Sécurité Alimentaire* - CSA) under the leadership of the Inner Affair Ministry, the committee is supported by the Niger Basin Authority, regional institutions (African Centre of Meteorological Application for Development - ACMAD, AGRHYMET) and the National Early Warning System of Mali - *Système d'Alerte Précoce* (SAP) delivering drought monitoring and forecasting information. Financed nowadays by the PRMC (*Programme de Restructuration du Marché Céréalier*), the SAP is based on a monthly data collection provided by provincial administration services and NGO´s. The members of the SAP meets on a monthly basis to publish national to regional bulletins and maps summarizing the monitoring agro-climatic shocks and their impacts on food production. Based on the common expertise, the committee establishes drought action plan and disseminates to the population via local radio and national television adapted information.

Drought mitigation and adaptation practices

- **Mitigation Measures**

According to the information available in deliverables D2.2 and D2.5, the common drought mitigation measures implemented during the historical droughts on these countries are presented in Table 11, according to the specific sector of application and to the type of measures.

Table 11. Compilation of drought mitigation measures implemented in Niger Case Study.

Sector	Type of measures	Description
Transversal measures	Social support/actions	Food distribution.
	Water recycling/management	Harvesting of run-off waters and restoration of water-points (exbow lakes, ponds and lakes).
Agriculture	Demand/supply management	Extension/popularization of improved varieties and suitable for the climate conditions of the main food crops (millet, sorghum, maize and rice).
		Farming in low land.
		Use of meteorological information for improving agricultural production and for contributing to food security.
Pastoral-livestock	Demand/supply management	Promotion of animal-feed and cereal banks.
		Popularization of animals more suitable for climate conditions.
Health	Social support	Establishment of an information system on risks of diseases associated with climate.

The Niger Case Study, in terms of mitigation measures, seems to have lower capacity/resources than state-of-the-art experience. As referred to the Eastern Nile case study, the Niger CS experience is targeted to avoid famine, and to minimize the impacts of droughts in agriculture and pastoral-livestock, rather than to prevent possible drought impacts.

- **Adaptation Measures**

The drought adaptation measures implemented on these countries are presented in Table 12, according to the specific sector of application and to the type of measures.

Table 12. Compilation of drought adaptation measures implemented in Niger Case Study.

Sector	Type of measures	Description
Transversal measures	Information and education	Sensitization and organization of the population for the conservation of natural resources (preparation of local reforestation and agro-forestry conventions).
		Preparation of a technological package for training the population in simples practices for adaptation to climate

Sector	Type of measures	Description
		change.
	Water recycling/management	Recycling of household and industrial waste waters.
		Protection of waters against of pollution of any origin (urban, industrial, agricultural waste).
		Integrated resources water management for taking account of the various users.
		Strengthening sub-regional cooperation in the field of transboundary resources water management.
	Impact management	Establishment of an early warning system.
		Promote the collection and management of hydro-climatic data.
Agriculture	Demand/supply management	Use of meteorological information for improving agricultural production and contributing to food security.
		Development of low lands.
		Introduction of applied research products in agriculture and livestock-breeding.
		Crop diversification; use of short-term varieties.
		Deepening of ponds, channels, and supplying canals of irrigable zone.
		Adoption of water conservation techniques (micro basins, etc.).
		Use of several types of water retention structures in the various rice-farming and pastoral border strips, such as small water retention structures, bunds and embankments, etc.
		Drawing up of the farming calendar depending on crops, through the research support.
	Financial issues	Decentralized financial systems.
		Setting up of micro-credit systems.
Pastoral-livestock	Water saving practices and management	Extension/popularization of animal and plant species more suitable for climate conditions.
		Organization of farmers communities and livestock-breeders communities for a rational use of space during the farming season.
		Deepening of ponds and construction of pastoral wells.
		Regular supplying with subsidized animal-feed.
		Intensification of animal feed resources ("borgou" farming, crop residues, fruit of "balanzan", etc.
		Construction of vaccination enclosures.
		Regular supplying with veterinary medicines.
		Popularization of artificial insemination tests (improvement of

Sector	Type of measures	Description
		local breeds).
Health	Social support and drought resistance/preparedness	Assessment of climate change real impacts on the health and well-being of the population.
		Training, sensitization, information and communication on the harmful effects of climate change on the health and well-being of the population.
		Setting up of a system for the prevention of and response to climate-sensitive diseases.
		Drawing up of plans for warning against extreme weather conditions with a view to preventing their effects on the population.

Moreover, regarding relevant strategies for agricultural responses, those include also farm-level adaptive responses, national agricultural development, global strategies of trade and investment, and activities to reduce drought vulnerability. Common farm-level adaptive responses include substitution of agronomic practices, altered inputs and agricultural development. The priority of the stakeholders is likely to be the smallholder farming sector. Commercial farms would be less likely to need assistance in these sorts of adaptive strategies. Also, when implementing adjustments, an attention has to be drawn in not entailing serious resource use conflicts between farming groups and others or within farming communities which implies a good implementation at community levels.

In what concerns adaptation measures, it can be noted that the measures applied in Niger case study are focused on protection of main sectors: agriculture and livestock, having a special attention to the famine issues and health.

However, the reality of Niger case study is still different from the state-of-the-art practices, and some actions could be taken, to improve this case study’s preparedness to droughts.

Community level adaptation strategies

Mobility and diversification

- Internal mobility in the Inner Niger Delta

The internal mobility in the Inner Niger Delta is a strategy which already belongs to traditional adaptive systems of the Inner Niger Delta communities. In the case of free submersion agricultural practices, farmers can select each year different location for the river-fed rice fields to try to adapt to the current annual flood patterns. Also, some fishermen adopt nomadic fishing practices to follow the fish migration paths through the delta. Finally, the selection of appropriate entries, trails and shelters to optimize grazing of the herds is also practiced by shepherds to adapt to the current change in annual flood pattern.

- Temporal and seasonal regional migration

This strategy is fully integrated into the nomadic culture of the population (Gallais, 1967). When severe and continuous drought periods occur, herders choose different routes and tend to migrate further to the south. In other sectors, fishermen can decide to migrate to other potential fishing areas (Quensière, 1994) (Sélingué reservoir) and farmers tends to settle in more secure crop fields (Office du Niger with fully governed irrigation schemes, Office du Riz Mopti and Office du Riz Ségou with controlled irrigation system plots). Finally, forming an important economic rural exode, male members of the household migrate temporally or permanently to urban areas to purchase financial means in other activities (gold mining, trade,…).

Evolution of activities

- Diversification

The Great Drought in the 1970s and early 1980s forced many rural people in the Inner Delta to abandon their specialization (Zwarts *et al.*, 2005). Fishermen started to grow rice on the side, while farmers began to fish and raise cattle as well. Some Fulani even began to cultivate rice. Such mixed ways of exploitation have become more prominent in recent years, and in fact have now been transformed into new professions (agro-pastoralist, agro-fishermen). Other diversifications are also considered (trade, gardening, transport) as current adaptive strategies to severe and continuous water scarcity episods adopted by locals (Bernus, 1995).

- Change of status in pastoral communities

Profound changes are observed (Cotula and Cissé, 2006) in the status of Fulani herders. More and more pastoralists lost their herds as they had often to sell the cattle which were not decimated to survive severe drought episodes. The owners are rich traders from cities investing in cattle for diverse reasons: prestige, distanced investment, back to the traditional roots when the person originates from the region. The shepherds still manage the herds but lost the ownership. The financing of the pastureland access in the Inner Niger Delta tends to support this evolution as shepherds needs to sell more cattle to get financial means.

3.2.4. Identification of risks increase on future drought hazards

Climate Change Impact

The Sahelian climate is one of the most variable on earth. The droughts of the 1970s and 1980s are reminders that climate has an impact on poverty and people's persistent vulnerability. Since the Sahelian climate is so irregular, its inhabitants have faced strong difficulties in investing and accumulating wealth (Barbier *et al.*, 2008). The outlook concerning climate variability is uncertain. Some studies based on global climate model projections suggest that climate variability might aggravate the situation of African agriculture. While global models disagree over future rainfalls, they all predict more variability in rainfall amount and distribution (Lebel *et al.*, 2000; Brooks, 2004; Marie *et al.*, 2007; Barbier *et al.*, 2008; Giannini *et al.*,2008; Zwarts, 2010b; Paeth *et al.*, 2011).

However, further studies of possible climate change impacts in the future, supposed to be explored in DEWFORA to support a more detailed analysis of this problem are not available in the moment.

Other sources of vulnerability

Explanations of the causes of the Inner Niger deltas' particular vulnerability are usually grouped in three main drivers that will potentially increase risks on future drought hazards, besides climate change and variability. One of the most commonly cited cause of vulnerability is increasing population density with simultaneous scarcity of resources (Zwarts *et al.*, 2005; Marie *et al.*, 2007; Barbier *et al.*, 2008). Projected population increase in the Niger Basin could well jeopardize current and future development efforts. The estimated basin population around 95 million in 2005 is expected to double by 2050 in the lowest scenario and could be multiplied by 4 if fertility remains constant (Clanet and Ogilvie, 2009). Current fertility rates exceed 6-7 children per woman and as mortality has started decreasing, demographic increase rates now exceed 3% per year. In countries like Mali (contrary to Ghana) fertility is not decreasing, resulting in a progressive rise in demographic increase rate. Future population trends will therefore depend on the speed of fertility decrease and the prevalence of pandemics such as HIV/AIDS. Clearly, the additional demand on water and food resources to feed up to 300 million additional people, added to the projected change, regarding diets, climate change, and water demand for industry and hydropower, will lead to significant pressure on natural resources and ecosystems and increase vulnerability of rural poor communities. This reality shows that communities are running into Malthusian crises, in which population density is too high and some carrying capacity or ecological equilibrium is exceeded. An increasing population cultivate the arable land until there are no more fallows, causing decline in soil fertility and crop yields. Because farmers do not have the means to adopt techniques to maintain this fertility, nor to intensify crop production or to feed their animals, yields remain low. Food crises tend to occur when some climate shock unveils an inherent lack of productivity. Sahelian pastoralism is encountering difficult problems as population growth leads to the expansion of cropland at the expense of traditional pastures (Barbier *et al.,* 2009). Many analysts believe that pastoralism is bound to disappear and is likely to be replaced by mixed crop–livestock farming systems, where livestock stay near the farms and provide milk, draft power, and manure for soil fertility. However, other studies suggest that mixed crop–livestock farming systems are less suited than pastoralism to the low and erratic rainfall patterns of the Sahel (Barbier *et al.,* 2009). Sedentary farming systems have limited means for coping with drought, while traditional pastoral systems, which rely on conducting animals to other regions that have received better rainfall, are much more able to handle droughts. The shift from pastoralism to more settled farming is driven in part by increasing population pressure and greater commercialization of agriculture. These forces create new opportunities as well as new needs for intensifying the farming system within rural communities. At the same time, these forces might also lead to greater enclosure and settlement of traditional grazing areas, leading to diminished access rights to these areas (Moorehead, 1997; Cotula and Cissé, 2006). Thus, the decline in traditional pastoralism can be seen as a cause as well as a result of diminishing access to transhumant grazing areas, and to a shift to increased cropping.

Other driver (which is partially linked to the previous) is the increase of upstream water intakes which tends to lead, like the climate change and variability, to a decline of the flooded area and thus directly impact on the productivity of the farming, fishing and livestock herding sectors, as well as the natural resources and the ecology (Kuper *et al.,* 2002; Zwarts *et al.*, 2005; Marie *et al.*, 2007; Barbier and Peter, 2009; Koch *et al.*, 2011).

Finally, there is also the political stability and governance factor that will not be detailed in this report as it remains still very uncertain. However, it should be noted that the undergoing conflict in Mali is crucial as it can evolve in many different perspectives and weaken at different degrees and scales the institutional building capacity.

3.2.5. Identification of local concerns expressed by Stakeholders

Similarly to the Eastern Nile case study, the local concerns expressed by Stakeholders focus on two main aspects: organizational and technical issues. Based on those concerns the main needs on each category (data related, management related, drought early warning systems, drought monitoring, forecasting and response, and climate change effects on drought risks) were identified.

Regarding data related concerns it was also referred the need to provide a higher density and data quality of monitoring (meteorological and hydrological) networks, e.g. to foster use of satellite data for gaps fill and to improve the coordination between the different institutions working on droughts and also between projects, programs, organizations, stakeholders and scales.

On management related concerns was also referred: the need to develop water governance policies for sub-basins; establish sub-basin Integrated River Basin Management (IRBM) organizations; develop knowledge base on river-related services and health; find an adapted balance of power among institutionalized and traditional representatives and among the different water users to converge the local actors into an integrative approach in the Inner Niger Delta respecting central authority and traditional regulations; and promote a lobbying with the authorities and the local and regional decision makers to defend a new paradigm for the Inner Niger Delta and to promote an institutionalized platform to negotiate appropriate trade-offs between upstream and downstream water use.

In what concerns drought early warning systems the existing gaps focus on the necessity to enhance the hydrological models to better represent upstream river basin management and the flood dynamics in the Inner Niger Delta; develop an early warning system to drought in the Niger River basin and especially in the Inner Niger Delta; integrate scientific early warning and forecasting system tools and drought assessment to reduce the effect of variability and strengthen the preparedness to drought; and combine the scientific knowledge with the traditional to reduce the effect of variability and strengthen the preparedness to drought.

Improving drought monitoring tools is also considered necessary, namely to address and support early warning and alerts to government, institutions, NGO´s and also to local stakeholders.

On drought forecasting the main issues pass through the improvement of the meteorological, hydrological and agricultural forecast, prediction of flood/runoff variability and of hydrological drought, according to upstream river basin management and to weather forecasting scenarios; application of a wider range of climate change projections and of weather forecast simulations to analyse the reproduction of hydroclimatic extremes; and provision of more reliable, specific information and understandable by local communities (e.g. for farmers use), such as to seed and localize river-fed rice field.

Regarding drought response the key concerns correspond to: the need to formalize the interactions of food security and ecological integrity with flood behaviour; extend the analysis from hydrological drought to socio-economic and ecologic vulnerability; explore emergency, mid-term and long-term adaptive capacities to organize the water management and uses for drought preparedness; develop new instruments and channels to disseminate and make accessible the information of drought impact assessment, drought forecast and adaption strategies to a large audience; simplify the content of forecast tools (bulletins, flooding maps, etc.) and ensure that they highlight potential actions/decisions that can be used by individuals and develop a trust relationship between communities and providers of climate information.

On climate change effect assessment the main need focuses on (i) coupling weather forecast and projected climate change simulations with a hydrological model through the application of downscaling and bias-correction methods; and (ii) developing vulnerability indicators to assess climate change and upstream management impacts on the main sectors dependent on flooding: farming, livestock herding and fisheries.

Finally, in what concerns adaptive capacities and planning, the main needs identified are:

- Establish a strong partnership between AFROMAISON and DEWFORA projects with the PPDDIN in order that environmental and natural resources plans benefit from the expertise and the results achieved.
- Consider the green economy in the alternatives for climate change adaptations
- Assess the hydrological capacity of the Niger River basin, regarding the possibility of irrigation of 65000 ha of PPIV (“small village irrigated perimeters”) planned by the PPDDIN (Sustainable development program of the DIN).
- Select pilot projects for each water use and identify adapted solutions to secure food production and biodiversity maintenance in a complex environment
- Take into account scenario of different political development in the different analysis

- Analyse institutional capacity building of the states in line with the development of all the models
- To make currently existing climate information (from seasonal forecast information to short-range weather advisories) widely available.
- Implement the adaptive capacities and planning developments in tandem with development and poverty reduction programs that strive to reduce the overall vulnerability of communities and enable them to build their resilience to all shocks (climatic, economic, social, political). Such programs are imperative to build the capacity of communities to act on received forecasts and empower them to link early information with early actions.

4. Recommendations for improvement of drought preparedness attending to CS characteristics

The first part of this chapter envisages a global analysis for both case studies as they have common identified features to be developed in DEWFORA, as presented in **Error! Reference source not found.**. The following topics present some recommendations on how can science be translated to policy and how can society be benefited.

Table 13. Specific features to be developed in DEWFORA for Eastern Nile and Niger Case Studies.

Features	Addressed in DEWFORA	Case-Study				
		Eastern Nile	Limpopo	Oum Er-Rbia	Niger	Pan-African
Improved Indicators	WP3	x		x		x
Impact of Climate Change	WP3	x			x	
Risk/vulnerability mapping	WP3	x		x	x	x
Meteorological Drought Forecasting	WP4	x	x		x	
Hydrological Drought Forecasting	WP4	x	x		x	
Agricultural Drought Forecasting	WP4		x	x		
Response to drought	WP5		x			
Enhanced DEWS and Mitigation	WP5		x	x		x
Preparedness and adaptation	WP5	x		x	x	

Attending to: (i) the current situation of societal capacities for drought management, (ii) the foreseen increase of risks, either due to possible climate change impacts, or to other sources of vulnerability, and (iii) the local concerns expressed by stakeholders, it is possible to delineate some recommendations, according to science available, for improvement of case study capabilities.

In general, for both case studies, more human resources (scientists, technicians and support staff) and appropriate infrastructures/equipment are required. It is necessary equipment and technology to generate usable/credible information; the involvement of scientist/specialists in Africa to design and develop early warning and forecasting systems (with advanced models and software) and to develop the drought monitoring, scientific analysis and research regarding climate. Moreover, the integration of scientific and local knowledge is indispensable; funding for research programs especially in water resources assessment could be advantageous and the collection, quality and sharing of data between institutions should be improved.

Regarding the organizational structures, some improvements could also take place, namely:

- A department/commission structure that deals specifically with drought;
- Structures for managing droughts at local level;
- Coordination and integration amongst institutions involved in drought management;
- Development of drought management policies and drought mitigation plans;
- Training and public awareness campaigns, the participation of stakeholders and water uses and the effective transfer of information to policy and decision-makers are important to improve drought mitigation and adaptation (more reliable, specific and understandable information).

In both case studies, it will be interesting to couple weather forecast and projected climate change simulations with a hydrological model through the application of downscaling and bias-correction methods. It should be applied a wider range of climate change projections and weather forecast simulations to analyze the reproduction of hydroclimatic extremes.

4.1. Case Study 6.1 – Eastern Nile

To prevent droughts and improve the drought monitoring and management capabilities at the Eastern Nile case study, it is important to overcome the difficulties associated with data collection and processing, and improve drought monitoring tools and early warning systems in general, as previously referred. The improvement of meteorological forecast and the operational and institutional capabilities is essential in order to define mitigation and adaptation measures for short, medium and long term preparedness and to provide reliable information to decision-makers and also to farmers. As detailed in chapter 4.3, at the global process the identification of vulnerability factors is also relevant.

On the other hand, in the Eastern Nile case study there is no institution responsible for river management at basin level. In this context and according also to the example of the Niger case study, a new organization operating at the overall basin area, responsible for water resources management and protection, could improve the situation regarding drought monitoring and management at the basin level. The declaration of drought situations, the adoption of adequate indicators, the monitoring of drought effects and the measures to be adopted in drought situations should be coordinated at basin level, although the existing specificities at national and local level should also be taken into account for the effective implementation of both drought monitoring and response.

4.2. Case Study 6.4 – Niger

As referred for the Eastern Nile Case Study, for Niger CS it is also important to overcome the difficulties associated with data collection and processing, and improve drought monitoring tools and early warning systems. In fact, it is necessary to develop a drought early warning system for the Niger River basin; to improve drought monitoring tools to address early warning and alerts to government; to clearly identify mid-term dry episodes and emerging crisis through tailored indicators; and to improve meteorological, hydrological and agricultural forecast. On drought response, it is important to explore emergency, mid-term and long-term adaptive capacities to organize the water management and uses for drought preparedness.

More specifically, some points should be mentioned, regarding different topics on drought monitoring and management, from the information made available by DEWFORA's case study partners:

a) Development of emergency plans:

- Increase the dialogue and cooperation between international donors, NGO´s and aid agencies with the Malian interministerial committee dealing with severe drought episodes and food crisis.
- Extend the prerogatives of SAP in Mali to coordinate the aid and the logistics of national and provincial authorities with international aid agencies and NGO´s.
- Maintaining strategic reserves of food allows the government (or marketing bodies) to dampen price fluctuations and release food in emerging crises. Quite large national reserves have been held in the past few decades, in some countries enough food to meet consumption for a year or more. In the 1990s, these reserves were reduced under structural adjustment agreements. International lending organizations noted that such reserves are costly to maintain and absorb a significant fraction of government resources. Better monitoring and more timely responses were seen as more efficient ways to cope with food shortages. Nevertheless, in the context of the Inner Niger Delta with a large interannual and seasonal variability in rainfall and flood volume, the creation of community-managed grain bank where residents have access to additional stores of staple crops, reducing food insecurity seems to be an appropriate answers to extreme drought cycle. In case of food shortage, the infrastructure to store food reserves is already in place and maintained at the community levels. This policy requires a better mediation between governmental services and the interministerial committee with international humanitarian

organizations and NGO´s to operate and collaborate efficiently during disaster years with local communities.

b) Improvement of sectorial resilience and productivity

b.i) Farming

- Apply resilient soil conservation techniques that improve soil fertilization and encourage the dissemination of adaptive techniques by training their peers
- Drought resistant crops and cultures substitution (dry rice) and quick-maturing seed varieties (sorghum and chickpeas)
- Promote 2 to 3 operational crop seasons by supporting a second campaign of rice and gardening and encouraging low-water and off-season farming

b.ii) Fisheries

- Promote fish farming in ponds
- Promote more efficient collect and storage techniques (to reduce losses after catching)
- Improve technics and equipment to smoke and dry fish
- Improve fish transport logistics and equipment from harbor to market place

b.iii) Livestock herding

- Promote plantation of pastureland (bourgou)
- Promote campaign to cut fodders in case of extreme dry episodes

c) Economic incentives

- Better access to micro-credit to invest in seeds, farming tools, fertilizers, regulatory fish boats and equipment
- Promote adapted and effective mechanism of insurance
- Biorights: protection of key biodiversity involving local communities supported by international community
- Encouraging the emergence of alternative solutions and activities to prevent wood overexploitation: other energy access (solar panel and electricity and cooker) if a program of tree plantation is followed by the community.

- Encouraging the emergence of alternative solutions and activities to prevent bird hunting: ecotourism when applied in a good way may offer alternative income but safety, facilities and a good organisation are essential for success, combination may be sought with other localities in Mali.

d) Restoration

- Apply resilient soil conservation techniques that improve dune fixation and natural regeneration with the encouragement to further disseminate adaptive techniques by training their peers
- Restoration of flooded bourgou pastures, flooded forests and dryland forests on the plains surrounding the delta with the development of local reafforestation and agroforestal conventions: flooding forests have key functions in the delta's ecosystem and economy (important spawning and growing area for fish population, crucial to the delta's (inter)national important biodiversity, important socio-economic functions and significance, protect against soil erosion caused by increasingly strong winds and rainstorms and increase the fertility of degraded soils)

e) Governance, planning and policy

e.i) River basin integrated vision

A capital prerequisite for the future of the flood-dependent ecosystem and economy of the Inner Niger Delta is the availability of water for the delta's flooding in particular during the flooding season, and this depends on the water management upstream. If there is much less water available the floodplain will be significantly reduced and so the production of natural resources. Communities are then forced to adapt themselves to this new paradigm leading to emigration and potential collapse of fish, fodder and crop production. Given the planned upstream irrigation, dams and reservoirs, in combination with climate change, a strategy should in the first place support the inclusion of the interests of the communities in the IND in the integrated water resources management of the Upper Niger Basin on a national and even transboundary levels.

- **Promote a lobbying** with the authorities and the local and regional decision makers to defend a new paradigm for the Inner Niger Delta and to promote an institutionalized platform to negotiate appropriate trade-offs between upstream and downstream water use (electricity, fully governed irrigation agriculture against fishery, breeding, free submersion and semi controlled irrigation farming, biodiversity maintenance and ecosystem conservation)

- Ensuring higher minimum discharges during low water periods: with the planification of new reservoirs and the projects of large extension of the irrigated schemes upstream the Inner Niger Delta, the hydrological regime tends to be more and more altered particularly the peak flood height and durations. Trade-offs analysis at the river basin scale with adapted dam management and water uptake rules from upstream irrigated schemes during exceptional annual drought cycle have to be further completed and finalized into an official agreement among representative of the government, cercles and sectorial stakeholders.
- Impact on the hydrological regime of the Inner Niger Delta has to be assessed for any projected upstream infrastructures and presented to the stakeholders of the IND in order to negociate compensation for the development of infrastructures supporting the adaptations
- Encourage upstream irrigation schemes renovation to improve efficiency and decrease water uptake “waste”. The Master plan of the Niger Basin Authority (BRL and DHI, 2007) considers many different options to implement new dams to generate hydroelectric powers and providing higher and then more continuous flow during the dry season in the fully governed irrigated schemes. However, really lower attention is given to improve the current irrigation efficiency of the large irrigation schemes (Marie *et al.*, 2007). In the Office du Niger, the rate is particularly low (0.2 to 0.3). Improvement and restoration of the current plots and its related irrigation infrastructures might save water that could be directed to new extensive plots. Managing water demand may require adjusting the institutions that price water and promote conservation. Analyzing the opportunity costs of water can identify cross-sectoral differences in water availability. The implementation of water pricing or other demand management tools (tradable permits, quotas) can encourage upstream actors to adopt more efficient practices.

e.ii) Provincial spatial planning and land tenure

- Spatial planning master plan for natural resources management at the commune and the Inner Niger Delta scales with stakeholders representatives from all the communities and sectorial activities.

- Clarify legal pluralism between customary and legal land tenure rights and regulations
- Decentralization and local empowerment

e.iii) Develop community level infrastructures

Farming

- Develop Pump-assisted total-water-management irrigation by encouraging motor pump rental or purchase
- Develop controlled-submersion flood-prone dips or bas-fonds with construction of dykes and weirs
- Improve the drainage systems in controlled irrigation schemes and prevent salinization with water flushing
- Creation of community-managed grain banks where residents have access to additional stores of staple crops, reducing food insecurity
- Creation of a community-managed bank of agricultural inputs and seeds, so that fertilizers are easily accessible, and farmer can increase yields

Fisheries

- Encourage the development of collective equipment and infrastructures: boat, nets, harbor, market place, smoked and dry fish equipment

Livestock herding

- Create community-managed hayloft to store fodder for the dry season and store “seed” to replant bourgou

f) Sectorial regulations and harmonizations from national legal framework to community level organizations and agreements

f.i) Organize trades

- Organization or reinforcement of fisherman, herder and farmer cooperatives (Bernus, 1995; Quensière, 1994)

f.ii) Fisheries

- Collective agreements on regulations of fish practices: materials allowed, mesh width, no lateral channels for fish catching, no bourgou 'fencing'…
- Collective agreements to limit fishing zones and forbid access to some areas to maintain the regeneration of the fish population
- Encourage collective investments and repairment of materials
- Introduce fishing licence with a mandatory registration to cooperatives
- Introduce fish warden and fine systems that ensure restricted access of fishing zone and the control of regulatory fish practices

f.iii) Livestock herding

- Harmonize the organization and the regulations between the different trails and shelters (Bernus, 1995)

4.3. How can science be translated to policy and how can the society be benefited

As above referred, there is a limitation of the available information for the case studies assessed and also a significant difference of the information available for both case studies, which, also, restricts a solid comparison of realities and, eventually, the extrapolation for the African reality, including the transboundary level. In this context, in this chapter it is made a general overview about how the theoretical concepts could be applied in the field and, adequately, benefit the society. For an ideal drought management it should be taking into account the following concepts and recommendations.

A science-based approach for preparedness and early warning is the key for later operational management and determines the success of DEWS. The drought management must be focused on prevention and minimization of the negative impacts of droughts on the economy, social life and environment and the main objectives are (Rossi, 2009):

- To ensure the water availability for essential human needs, guaranteeing population's health and life;
- To prevent or minimize negative effects on economic activities;
- To avoid or minimize negative drought impacts on the status of water bodies.

The science available regarding drought monitoring and forecasting systems, the basis for the development of drought early warning systems and drought mitigation and adaptation measures, can contribute significantly regarding the improvement of the different steps of the drought management cycle, Figure 10.

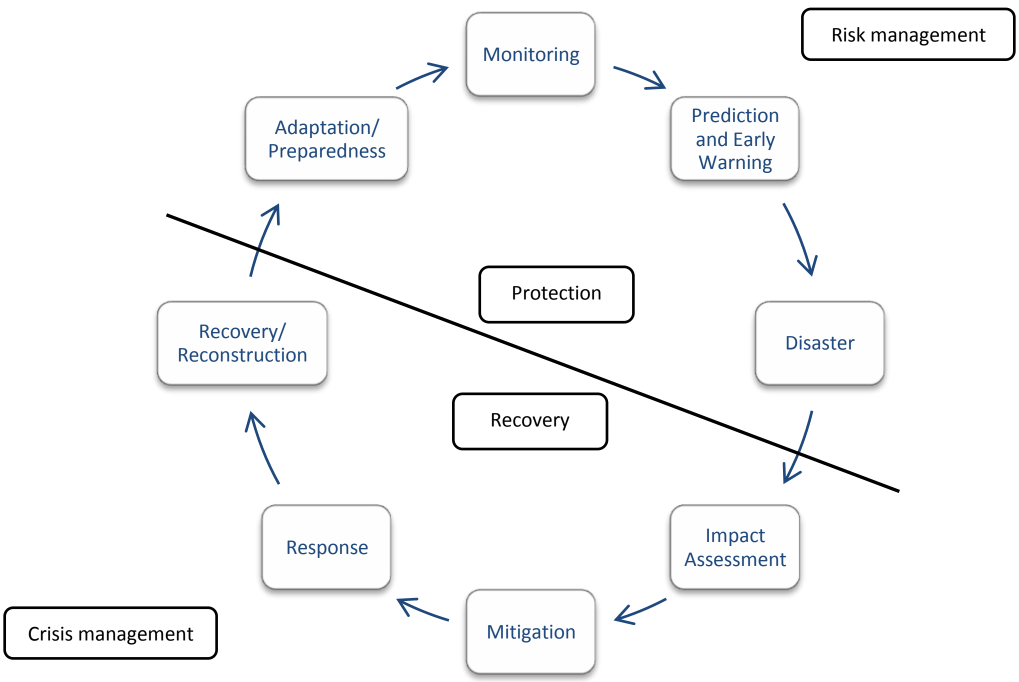


Figure 10. The drought management cycle. Adapted from (Wilhite and Svoboda, 2000)

The management of droughts needs a strong technical component but also a good knowledge about how to implement/apply this information to each reality. In this context it shall be taken into account that the risks associated with drought for any regions is a product of both region's exposure to the event (i.e., probability of occurrence at various severity levels) and the vulnerability of society to the event.

The better understanding of the regional climatology and the characterization of historical meteorological/ hydrological parameters will provide critical information on the frequency and intensity of historical events. Complementarily, improved understanding of regional social characteristics/vulnerabilities will provide information to decision making in order to minimize the impact of droughts. In the context of a drought early warning system, the focus on vulnerability may prove to be very effective since it includes the evaluation of the capacity to anticipate and compensate the adverse effects of drought. If a drought forecast is available, drought managers can gain time and include the occurrence of potential drought impacts in their analysis.

The vulnerability is a measure of the possible consequences to be suffered by a system if exposed to a certain hazard. Under the DEWFORA approach, vulnerability is considered to be a function of susceptibility to droughts and respective coping capacity.

Vulnerability to droughts is determined by natural factors, like the intensity and magnitude of the drought hazard, and also by social factors like those that lead to exposure, but the coping and adaptive capacities as well. As these characteristics could change over time, it is possible to say that droughts in the same region will have different effects, even if they are identical in intensity, duration and spatial coverage.

In order to characterize drought vulnerability in the context of drought early warning systems, it is useful to distinguish between two types of indicators that can be considered: hazard indicators and vulnerability indicators.

Hazard indicators describe nature-based determinants: meteorological, hydrological and agro-ecosystems, and are used to characterize the occurrence of drought. Depending on the focus of the analysis, hazard indicators may be classified in two groups: diagnostic, if the emphasis is placed on drought identification and monitoring, and predictive if the emphasis is placed on drought early warning. Some examples of hazard indicators are the percentage of normal precipitation, SPI, PDSI, CMI, among others.

Vulnerability indicators describe social-based responses: anticipation, adaptation and reaction to drought and are essential to implement effective drought early warning system. Their focus is on drought impacts on society. Thus, for designing an early warning system it is important to understand the main impacts or susceptibilities of drought in the basin. The relevant drought impacts considered for each river basin may be characterized, such as impacts in the hydrology, the agriculture or other economic sectors and impacts in the environment. Regarding vulnerability indicators, some of them are listed below:

- Earth observation indicators (e.g. vegetation health index)
- Water resources and water infrastructure indicators (i.e., vulnerability in water supply and irrigated systems is directly related to water scarcity, which differs from drought because it is related to a shortage of water availability to satisfy demands)
- Agriculture (e.g. cultivated area, arable land, permanent crops, irrigation potential)
- Population (e.g. population density, economically active population, economically active population in agriculture)
- Development indicators (e.g. access to water and sanitation, infrastructure vulnerability index)

– Drought vulnerability index (e.g. natural resource structure; the economic capacity – GDP per capita, energy use; the human and civic resources - Adult literacy rate, life expectancy; and the aspects of agricultural innovation)

In parallel with the study of vulnerability indicators, some thresholds should be defined. A threshold is the value at which action is initiated – and not necessarily that at which problems occur. With these indicators and their respective thresholds, it is possible to define a classification of risk levels in agriculture or other sectors like ecosystems and water supply systems and authorities may act according determined priorities and the risk levels obtained.

The flow chart for evaluating vulnerability is presented in Figure 11.

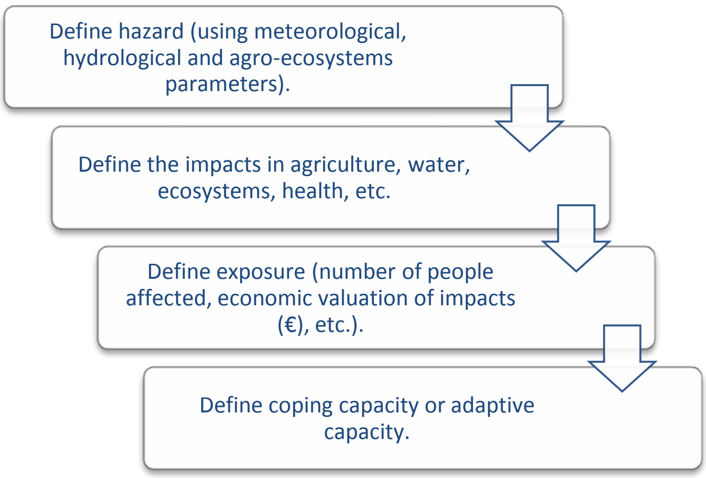


Figure 11. Flow chart for drought vulnerability evaluation.

With the previous analysis it is adequate to outline the global drought management process, from science application, like the development of drought early warning systems, and evaluation of vulnerability, to the policy and decision-making phases, as well as the communication with population in general. This global process includes the following aspects:

– Drought monitor and forecast;
– Evaluate the vulnerabilities of the region;
– Define the actions to be taken upon drought, establishing priorities during water scarcity situations;
– Evaluate the better procedure to implement the actions, the political process, and the links between drought, water and development policies;

– Define the way to ensure communication (provision of information to potentially affected groups - final step for effective implementation of DEWS).

Figure 12 illustrates the relation between the different types of drought, the different components of a DEWS (including the monitoring and forecasting and also the vulnerability components) and potential actions to be implemented in the perspective of drought preparedness and assessment. This relation can be followed to link the science (risk analysis) to policy (operational component).

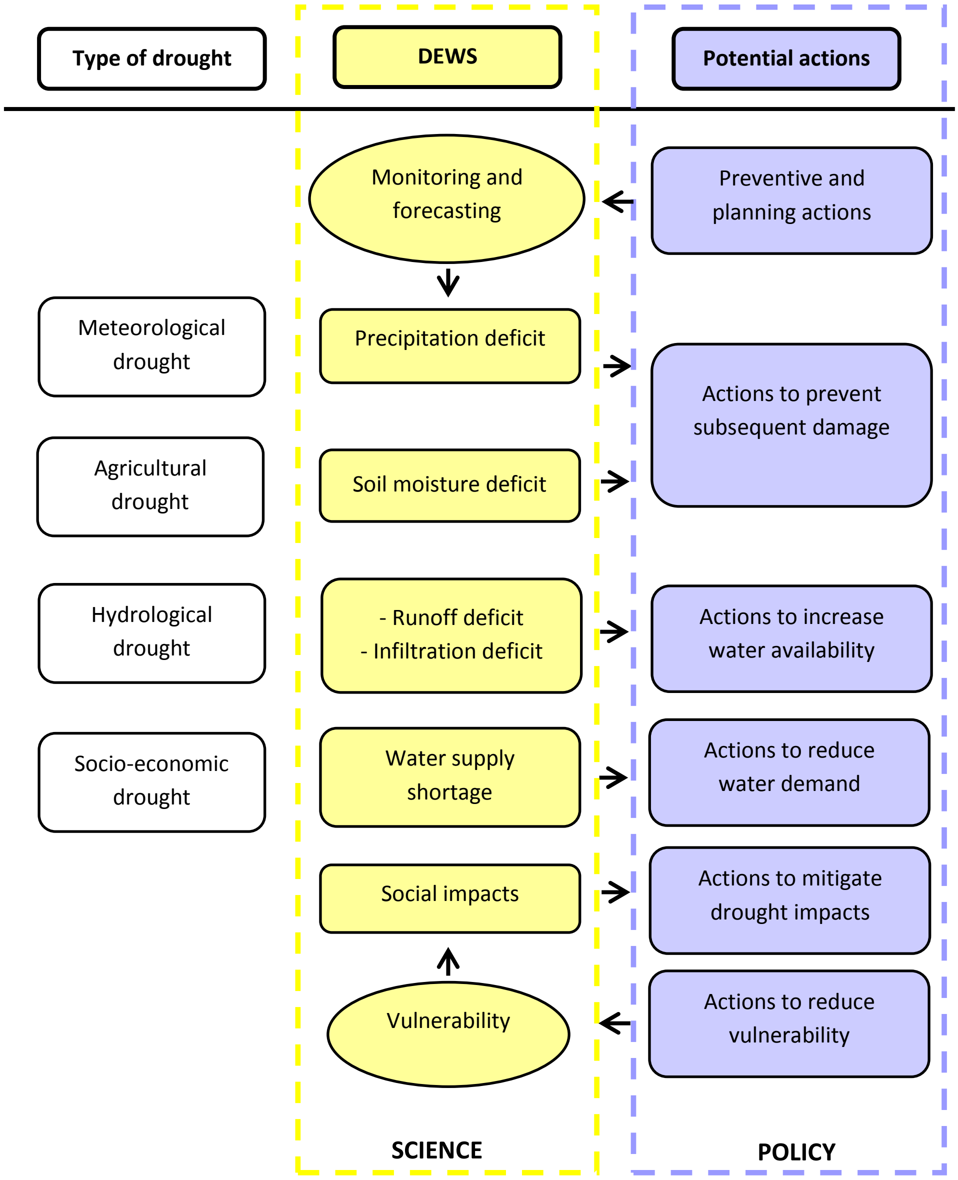


Figure 12. Relation between types of drought, DEWS, and the potential actions that may be implemented. Adapted from D5.1.

Thus, some generic examples were provided on how can the science can be translated to policy and, subsequently, benefit population, since it contributes to the implementation of different types of actions: drought prevention, which concerns those measures aimed at preventing drought causing damage; and drought preparedness, which concerns those measures which enable societies to respond rapidly and adequately to drought.

5. Main findings and conclusions

This report provides DEWFORA project's recommendations on technical development for drought monitoring, forecasting and response for African reality, based on the Eastern Nile and Niger case studies, and according to the state-of-the-art methodologies of the experienced countries: Europe, USA and Australia.

Some gaps were identified in the Eastern Nile and Niger case studies. Thus, some improvements are recommended since those can be very important in what regards drought preparedness and response. More specifically, for these two case studies is, first of all, recommended that the identified deficits regarding data quality, data sharing, limited skills, including human resources/knowledge and also technical resources could be minimized/eliminated. Also, some specific recommendations are indicated, especially for Niger case study, including some recommendations on preventive and mitigating actions that could be applied, for which more available information was provided. Finally, some state-of-art recommendations are made focusing on how can science available can be translated to policy and benefit society.

Nonetheless, it should be enhanced that the "state of the art" practices should also incorporate the local knowledge and the forecasting and early warning systems should be adequately implemented. Regarding institutional frameworks for drought mitigation, they mostly involve institutions which provide agriculture extension services, food aid, policy direction and funding, which were, also, the main focus of the drought mitigation/adaptation actions usually applied in those areas. In these cases, it seems fundamental the creation of an institution responsible for drought management at river basin level based on "state-of-art" drought monitoring forecasting and early warning methodologies (especially for the Eastern Nile case study).

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

Thus, it is important to remind that the region vulnerabilities, taking into account the increased hazard due to climate change, should be considered for definition of adaptation measures.

In fact, it is possible to conclude that, in these two case studies, and probably in all African countries, the improvement of meteorological and hydrological forecast and the operational and institutional capabilities is essential, complemented with the definition of mitigation and adaptation measures for short, medium and long term preparedness. With these measures, linked to the monitoring and forecasting results, the African countries would be better prepared.

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